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THE SOUTH POLAR CAP OF *MARS*.

By E. E. Barnard.

However much the general surface features of *Mars* may be misrepresented, and however much the canals, single and double, may be illusory, the polar caps seem to have escaped this general deluge of uncertainty and misrepresentation.

They stand for their face value, whatever may be their composition. There seems yet no definite proof that they are not as much ice and snow as that with which we have to deal in our own terrestrial winters. So much is at least suggested by the great seasonal changes they undergo from winter to summer.

The south polar cap is the better known of the two, because of its more favorable position for observation at the near approaches of *Mars*. The changes in its dimensions have been recognized since the earliest telescopic observations of the planet, and the early supposition that they were due to accumulations of snow during the winters of *Mars*, which melted away at the approach of summer, is as good a theory as any of those put forward today to explain the phenomenon.

During the close approach of *Mars* in 1892 and 1894 the writer had a good opportunity to study the planet at the Lick

Observatory with the 12-inch and 36-inch refractors. A carefu series of drawings was made at that time, but they have not yet been published.

Struck with the great changes that take place in the polar caps, I decided to make a series of micrometer measures of the south cap, instead of remaining content with estimates and drawings of the phenomenon, though a great number of drawings were made of the cap—some sixty of which were published in *Popular Astronomy* for June 1895 (**2**, 433–443).

It would seem that the changes in the dimensions of these caps have always been studied from drawings and never from a systematic series of micrometer measures. While these changes can be fairly studied from careful drawings, there must always remain a large percentage of uncertainty, especially if the drawings are by different observers; careful micrometer measures are therefore always to be preferred, as changes indicated by them can be relied upon.

Following are the measures of the cap at the oppositions of 1892 and 1894. The time is $8^h\ 0^m$ slow of Greenwich. The column headed "Days" is the number of days before or after the summer solstice of the southern hemisphere of *Mars*. The measured diameter is given under the heading "Observed, while the values under "MΔ" are the diameters reduced to the mean distance of *Mars* = 1.52369. Under the head "Residuals" the difference of each observation from the curve is given.

1892.

(Made with the 12-inch refractor.)

Date		Days	Observed	MΔ	Residuals
July	$3^d\ 15^h\ 25^m$....	−102	9″.31	2″.78	−0″.12
	8 13 11	97	10.08	3.06	+0.20
	15 12 55	90	9.97	2.67	−0.05
	22 13 35	83	9.90	2.52	−0.05
	31 12 40	74	10.02	2.49	+0.19
August	2 11 20	72	8.76	2.17	−0.10
	3 11 0	71	8.50	1.75	−0.13
	3 13 40	71	8.86	2.10	−0.42
	4 11 50	70	8.48	2.10	−0.11
	5 11 45	69	8.70	2.16	0.00
	7 11 25	67	8.17	2.02	−0.07

1892.—*Continued.*

(Made with the 12-inch refractor.)

Date	Days	Observed	M Δ	Residuals
8 10 35	−66	8.75	2.17	+0.10
9 11 30	65	8.38	2.08	+0.05
10 10 30	64	7.91	1.96	0.00
11 12 20	63	7.89	1.98	+0.01
12 11 40	62	7.99	1.99	+0.06
14 10 42	60	7.93	1.99	+0.11
17 9 30	57	6.59	1.67	−0.05
18 12 5	56	7.13	1.79	+0.07
19 12 35	55	7.13	1.82	+0.12
21 11 45	53	6.71	1.73	+0.17
23 9 42	51	6.73	1.75	+0.20
September 2 10 10	41	3.62	1.01	−0.25
4 7 50	39	3.80	1.08	−0.12
6 9 30	37	2.81	0.81	−0.35
8 8 6	35	4.44	1.11	0.00
9 8 22	34	3.54	1.05	−0.06
9 11 0	34	3.65	1.08	−0.05
11 8 25	32	3.45	1.04	+0.05
16 7 40	27	3.75	1.19	+0.22
19 8 20	24	2.95	0.96	+0.08
22 6 50	21	2.94	0.99	+0.15
23 7 30	20	2.12	0.72	−0.14
October 7 7 27	− 6	1.82	0.71	+0.07
November 6 6 20	+24	0.60	0.31	−0.07

1894.

(Made with the 36-inch refractor.)

Date	Days	Observed	M Δ	Residuals
May 21^{d} 16^{h} 1^{m}....	−103	3″.84	2″.79	−0″.02
28 16 0	96	3.66	2.58	−0.10
June 11 16 0	82	3.81	2.46	+0.07
18 15 20	75	3.69	2.28	0.00
24 15 50	69	3.55	2.10	−0.02
25 15 25	68	3.71	2.18	+0.06
July 1 16 0	62	3.66	2.07	+0.15
8 16 30	55	3.56	1.92	+0.22
15 15 5	48	2.25	1.15	−0.35
30 13 50	33	2.99	1.37	+0.19
August 5 16 50	27	2.16	0.94	−0.11
6 13 40	26	2.24	0.97	−0.05
13 17 55	19	2.95	1.21	+0.28
26 13 55	− 6	1.65	0.61	−0.10
September 2 12 30	+ 1	2.17	0.76	+0.12
9 12 10	8	1.52	0.50	−0.09
16 14 45	15	1.75	0.55	+0.02
30 11 10	29	1.14	0.33	−0.02
October 7 9 40	36	1.43	0.41	+0.05
8 10 30	37	1.49	0.42	+0.06
November 11 9 35	71	0.33	0.11	−0.10

In recently looking over these measures of the south polar cap, it occurred to me that if they were plotted with respect to the summer solstice of the Southern Hemisphere of *Mars*, and if curves were drawn through them, the results might be very instructive. The two curves that accompany this paper have therefore been prepared in that manner.

The measures are all reduced to the mean distance of *Mars*, and hence are strictly comparable. In the diagrams the vertical scale represents the diameter of the cap in seconds of arc, while the horizontal scale gives the time in days before and after the summer solstice of the southern hemisphere of the planet.

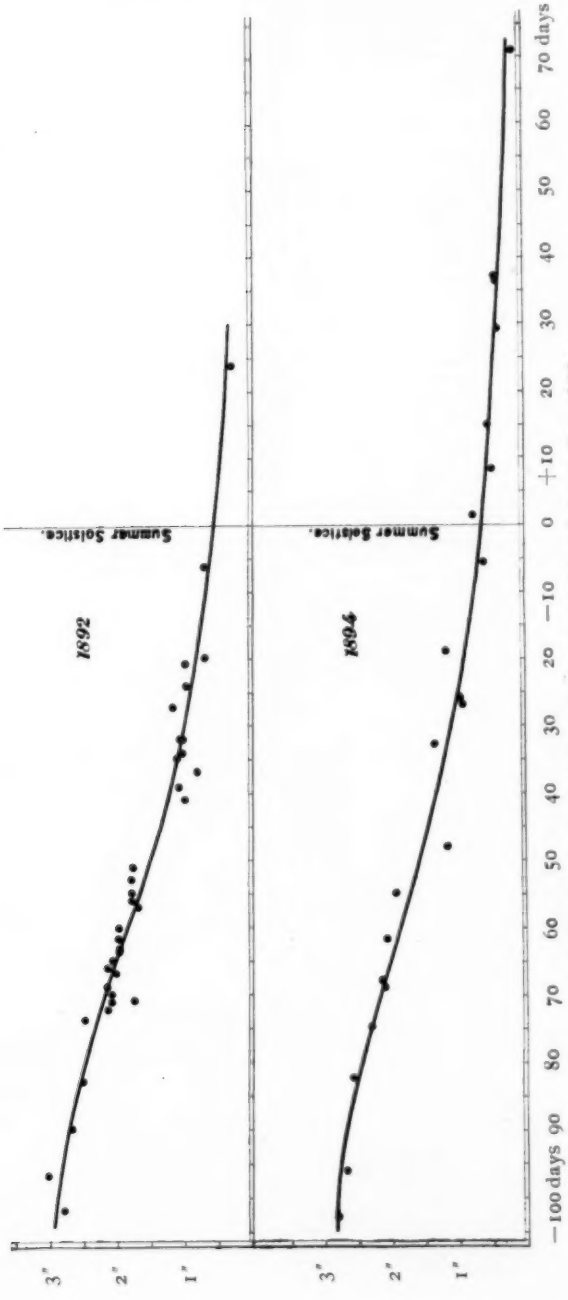
At first sight the striking fact is apparent that these two curves are parallel throughout. The cap, therefore, at both oppositions, followed the same law of decrease with surprising closeness.

Another important feature, to which I have already called attention in the number of *Popular Astronomy* referred to, is that the cap continues to diminish after the summer solstice, or beyond the time when the greatest heat is received from the Sun, showing, as in the case of the Earth, that the highest temperature is not reached until several months after the maximum of solar heat. This may have considerable bearing upon the presence of a Martian atmosphere.

There seems to be a general belief now that *Mars* certainly has an atmosphere. This atmosphere seems to be very much less dense than our own, and yet it is of sufficient density to produce the phenomena of the polar caps by condensation and evaporation, and also to produce, though rarely, some form of clouds.

The maximum diameter of the cap is perhaps shown by my measures, as the Sun had only risen on the south pole some four or five weeks earlier, and the curves do not seem to indicate that there was any sensibly larger diameter for the short interval between the rising of the Sun and the beginning of the measures.

It would be very interesting to watch the growth of the south cap to see if the increase follows the same law as the decrease.



Curves showing diminution of diameter of South Polar Cap of Mars.

Ordinates: Measured diameters of cap. Abscissae: Days before and after Martian Summer Solstice.

It seems, however, that the increase can never be seen. Though the planet was carefully watched in 1894, nothing was visible of the cap after November 19. It seemed to have entirely disappeared. Records of its non-visibility were kept as late as May 12, 1895. After the middle of February, however, it would have been immersed in the shadow, as the Sun, after that date, would pass too far north to shine on it. Hence, if we take these observations as a criterion, it will not be possible to watch the growth of any portion of the cap at any time.

On several occasions a portion of the outline of the polar cap was lost by a dusky obscuring medium which would eventually clear away and the outlines would then again become distinct. There seemed to be good reason for believing this temporary obscuration to be of the nature of clouds.

In May of 1894 the polar cap covered an area of about 365,000 square miles. By the last of November it had all disappeared, having apparently melted entirely away.

The rapid decrease of the polar cap shows that the snow, if snow it be, cannot be of great depth. It is probably a more or less thin sheeting, just as in winter here on the Earth the ground will be sometimes covered with snow down beyond middle latitudes, which may in the course of a few days melt away, producing a rapid change in the apparent extent of the Earth's polar cap as seen from, say, *Venus*.

The following table gives the diameter of the south polar cap for every five days before and after the Martian summer solstice, taken from the curves of 1892 and 1894. It will be seen that the difference is very small, not exceeding 0".08. Whether the change of sign is due to a real difference in the diminishing of the cap in 1892 and 1894 it is not possible to tell—the quantity involved in the apparent change is too small to deal with in measures of this kind, and can well be attributed to errors in drawing the curves. From the strikingly close agreement of the curves at the two seasons, it would appear that the mean curve indicated in the last column would serve as a means of predicting the mean diameter of the cap with great exactness—indeed, with greater accuracy than it can be measured. Of

course, this is a statement resting on only two Martian years, but I believe the changes in these caps, apparently uninterrupted by freaks of weather, and depending probably on the position of the Sun alone, follow a perfectly regular law which is shown by these curves, and which permits an accurate prediction of the mean diameter of the cap.

DIAMETER OF THE SOUTH POLAR CAP FOR EVERY FIVE DAYS, TAKEN FROM THE CURVES OF 1892 AND 1894.

No. Days before Summer Solstice	1892	1894	Difference	Mean Curve
100	2″.90	2″.85	+0″.05	2″.87
95	2.83	2.77	+0.06	2.80
90	2.74	2.70	+0.04	2.72
85	2.61	2.57	+0.04	2.59
80	2.50	2.42	+0.08	2.46
75	2.35	2.31	+0.04	2.33
70	2.20	2.17	+0.03	2.19
65	2.04	2.01	+0.03	2.02
60	1.86	1.87	−0.01	1.87
55	1.69	1.73	−0.04	1.71
50	1.53	1.56	−0.03	1.54
45	1.37	1.43	−0.06	1.40
40	1.24	1.30	−0.06	1.27
35	1.12	1.20	−0.08	1.16
30	1.02	1.09	−0.07	1.06
25	0.94	0.98	−0.04	0.96
20	0.84	0.91	−0.07	0.88
15	0.77	0.82	−0.05	0.80
10	0.70	0.75	−0.05	0.73
5	0.64	0.68	−0.04	0.66
0	0.58	0.63	−0.05	0.60
After 5	0.52	0.60	−0.08	0.56
10	0.48	0.56	−0.08	0.52
15	0.44	0.52	−0.08	0.48
20	0.41	0.49	−0.08	0.45
25	0.37	0.45	−0.08	0.41
30	0.35	0.42	−0.07	0.39
35		0.39		
40		0.35		
45		0.32		
50		0.30		
55		0.27		
60		0.25		
65		0.24		
70		0.23		

The outline of the polar cap was often irregular. Details were frequently visible upon its surface in the form of bright spots, broad bright lines, and changing dark spots. A large temporary dark spot was visible near the middle of the cap at both

oppositions when the cap was at its largest. This seemed to disappear as the cap became smaller. On one occasion this central marking on the cap was of a reddish hue, like the general surface of the planet, and on several dates the cap was distinctly double.

The most striking phenomenon connected with the cap, however, and perhaps the most important, was the recurrence of a projection from the edge of the cap, which appeared at the same point in both years, and which was left behind as a bright strip as the cap diminished, showing it to be due to some local peculiarity of the surface of *Mars*. It was suggested at the time that this might be caused by a group or range of mountains at that point on *Mars*. If these were mountains, the snow on their summits would remain stationary as a white strip, after the receding cap had left it, until it melted. Thus the decay of the polar cap probably reveals to us the existence of mountains on *Mars*, which would otherwise remain unknown.

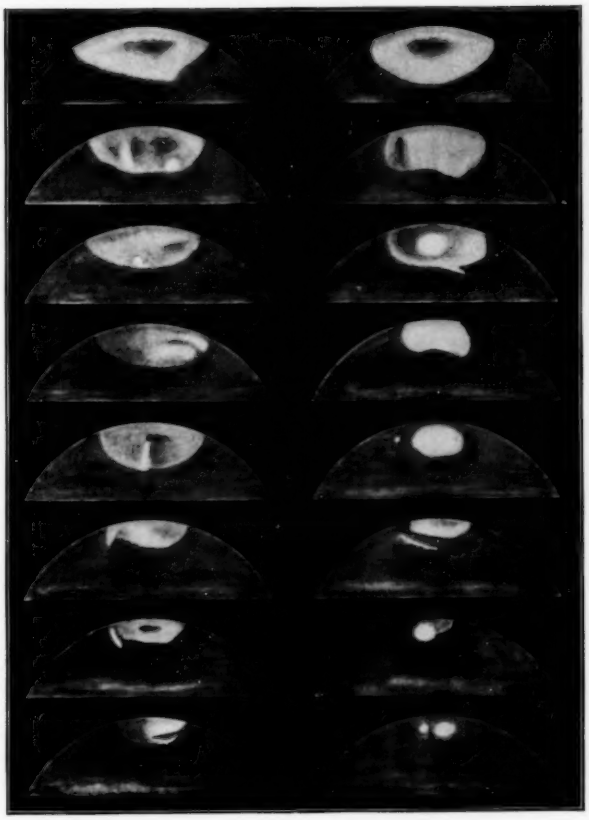
In tracing back this phenomenon through former oppositions it was found that this very thing had been seen by Mitchel at Cincinnati in the year 1845 at the same point on the surface of *Mars*. It doubtless repeats itself every Martian year when the cap is diminishing.

It is possible to predict when it will be visible from the Earth. It begins to appear about sixty days before the Martian summer solstice, and is passing through its changes for about a month. It ought to begin to be visible when the heliocentric longitude of *Mars* is about 320°. When more careful and continuous observations have been secured, its reappearance ought to be predicted very closely.

Since writing the above I have consulted the classical paper by Mr. N. E. Green in the *Memoirs of the Royal Astronomical Society*, Vol. XLII, where he has given a series of twelve admirable drawings of *Mars*[1] (made at Madeira in 1877), with a map

[1]Mr. Green mentions that these twelve are selected from forty-one drawings of the planet made by him in 1877. These splendid drawings, which so faithfully represent the telescopic appearance of *Mars*, should all be made available to those interested in the planet. In these days of half-tone work their accurate reproduction would be inexpensive.

PLATE XVIII.



THE SOUTH POLAR CAP OF MARS.

of the surface of the planet. In his paper Mr. Green calls attention to the repetition of the projection from the south polar cap (the same shown in my drawings) and offers the same explanation for its cause, *i. e.*, a mountainous surface. One of these bright spots he has named "Mitchel Mount," in honor of Mitchel, of the Cincinnati Observatory, to whose drawings we have referred.

The north cap in 1895 was well seen, clear, and distinct on May 6. Evidences of it had been seen several months earlier. A note on December 23, 1894, at 6^h says: "there is a strong bluish white glow at the north limb, but no definite polar cap." This glow was frequently noticed thereafter until the true cap made its appearance.

To show some of the peculiarities of the outlines of the cap and of thedet ails upon its surface, eight drawings for each of the seasons, 1892 and 1894, have been selected for reproduction here (Plate XVIII). No effort has been made to retain any of the details of the surface of the planet near the caps, as such details would more properly belong to the drawings of the planet itself.

One drawing of the planet is also given (Plate XVII), as a sample of the details visible in 1894. In many of the drawings secured at that opposition, when the planet was well seen, the details were so abundant and complicated, especially in the dark regions, that it was impossible to correctly delineate them.

YERKES OBSERVATORY,
April 2, 1903.

CATHODO-LUMINESCENCE AND THE NEGATIVE POLE SPECTRUM OF NITROGEN.

By PERCIVAL LEWIS.

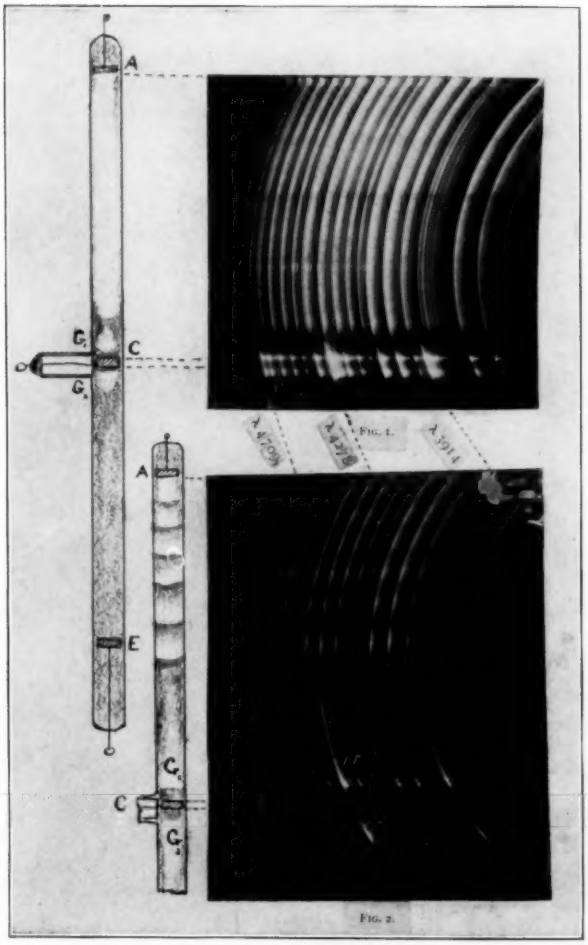
I. A STUDY OF THE NEGATIVE GLOW.

IN a previous paper[1] it was shown that the vapors of a number of metals can be made luminous by the action of cathode rays alone, precautions being taken to prevent the passage of a conduction current through them. It has been suggested by several investigators that the characteristic negative glow observed in vacuum tubes containing certain gases, notably nitrogen, is likewise the direct effect of the energy absorbed from the cathode rays by impact or otherwise. In the case of volatile metals it is easy to isolate their heavy vapors by heating the metals at one end of a long vacuum tube. Their slow diffusibility and rapid condensation on passing beyond the heated region prevents them from raising the pressure of the highly rarified atmosphere around the distant cathode, from which the rays are projected into the mass of vapor. Such a method is obviously impossible in the case of light and rapidly diffusible gases, such as nitrogen. In such cases complete isolation from the region traversed by current can be secured only by a very thin metal partition, as in Lenard's experiments,[2] and then, as shown by Lenard, the luminosity produced is too small to be examined spectroscopically. Such luminosity does exist, however, although it cannot be positively identified with the negative glow. The only practicable method of showing that the negative glow is due altogether to cathode rays seems to be an indirect one — by comparing those parts of the negative glow through which it is likely that little or no current flows with those parts through which the greater part of the current flows. If no difference is found in the luminosity, either qualitative or quantitative, it would seem

[1] P. LEWIS, ASTROPHYSICAL JOURNAL, **16**, 31, 1902.

[2] *Wied. Ann.*, **51**, 229, 1894.

PLATE XIX.



exceedingly probable that the luminosity in this part of the tube is due to cathode rays solely.

Since there is convincing evidence that cathode rays consist of negatively charged particles, it may be asked whether the continuous projection of such particles does not in itself constitute a convective electric current; for it is generally taken for granted that the current through the positive column is also transported convectively, by some process akin to electrolytic conduction. There are, however, at least two grounds for differentiation between the two processes: (1) the cathode discharge at low pressures takes place in all directions normal to the cathode, with absolute indifference to the position of the anode, while the positive column, like the ordinary electric current, takes the shortest or least resistant path between the electrodes; and (2) the cathode rays seem to consist of subatomic corpuscles, while such evidence as we have indicates that the positive electricity travels with particles of atomic magnitude, as in the case of electrolysis.

A straight tube of about 6 mm internal diameter was used. (See Plate XIX.) The cathode C was in the middle, the anode A near one end, and an idle electrode E (usually earthed through a high resistance) at the other end. The distance between the electrodes was about 7 cm. They were made of thick disks of aluminum, and nearly filled the cross-section of the tube. A Leeds induction coil giving a very heavy spark about 6 cm long was used. The nitrogen was prepared by heating a solution of ammonium sulphate and sodium nitrite in molecular proportions, and was freed from oxygen, carbon dioxide, and water vapor by passing it in succession through pyrogallic acid, concentrated potassium hydrate solution, and a train of drying tubes.

It is, of course, well known that the direction of the negative glow is independent of the position of the anode. It has not, perhaps, been sufficiently emphasized that when the cathode has sufficient free space on both sides the glow is perfectly symmetrical, and is just as large and intense on the side opposite the anode as on the same side. This is true when the cathode almost closes the tube, but not when it entirely closes it. The

glow G_2 resembles G_1 in form, size, and intensity, whether all three electrodes are insulated, A alone earthed, or A insulated and C and E both earthed. The only difference observed was that at very low pressures in the latter case there was a division of the negative discharge between C and E, with a short independent positive column between them; but even in this case the discharge from C was perfectly symmetrical.

The luminosity of G_2 was apparently equal to that of G_1 at all pressures. This was tested by throwing an image of each in succession on the slit of a Glan spectro-photometer and measuring the intensities of the three bright negative pole bands λ 5228, λ 4709, and λ 4278 at equal distances on each side of C through a wide range of pressures. At low pressures and at considerable distances from the electrode the luminosity was small and measment difficult; but up to distances of 2 cm from C at a pressure of about 1 mm there seemed to be equality of intensity on each side, within the range of experimental error. This symmetry is also clearly shown on photographs to be described later.

With this form of tube it would certainly be incorrect to say that no conduction current passes from the anode to the farther side of the cathode, and consequently through G_2. This is shown by the fact that when C completely closes the tube, except for a small tortuous channel to permit equalization of gas pressure, there is no negative glow on the farther side, as there should be if the negative glow were independent of the existence of the anode within the same inclosure, as well as of its direction. The greatest resistance to the discharge is at the cathode, and at low pressures we may expect that every available part of its surface will be equally brought into requisition to facilitate the discharge, even though the diverted part of the conduction current be forced to take a very roundabout and constricted path to the rear of the cathode. It seems likely, however, that the greater part of the current will pass directly to the nearer side, and that the diverted part, after passing around the cathode, will take as short a path as possible to its surface; and yet the intensities of the negative glow on the two sides is the same not only near the cathode, but at distances as great as 2 cm. The matter is com-

plicated by the fact that the canal rays discovered by Goldstein[1] and shown by Wien[2] to consist of projected positively charged particles, coming probably from the anode, pass readily through openings through and around the cathode, and may take some unknown part in the processes going on in that region. The canal rays, however, have not been observed at pressures of more than a few tenths of a millimeter.

In order further to vary the conditions, a completely closed wire-gauze cylinder was inserted between E and C, touching the former and ending about 5 mm from the latter. The negative glow penetrated the meshes of this cylinder, without any apparent changes of either intensity or length. In most cases C was earthed by a wire and E by contact with a wooden table, so that static discharges might escape from the latter without any appreciable conduction current.

The effects of the electrostatic forces acting between C and the gauze cylinder and the walls of the tube must not be overlooked, and there can be little doubt that some discharges through this region must have resulted from them. They were never sufficiently strong to cause visible luminosity.

Thus the currents through G_2 must have been small compared with that through G_1; furthermore, the conditions were so varied that there must have been great relative changes in the intensity of these small currents—and yet G_2 remained exactly like G_1. There seems to be no escape from the conclusion that the negative glow is independent of current and dependent upon some other form of discharge, and no alternative to fixing the responsibility upon the cathode rays.

An arrangement was next devised for photographing the spectrum of all parts of the tube simultaneously, in order that any local differences might be more clearly shown and recorded. A metallic slit about 15 cm long was placed immediately in front of the discharge tube and parallel to it. By means of two lenses of about 30 cm focal length, one simple and the other achromatic, and a large Rutherfurd compound prism, a spectrum was thrown on a photographic plate. The arrangement was

[1] *Berichte d. k. Akad. Berlin*, 1886. [2] *Wied. Ann.*, **65**, 446, 1898.

crude, and not capable of accurate or permanent adjustment; nevertheless some of the results, especially those dependent upon altering the nature of the discharge, are, perhaps, of sufficient interest to warrant the reproduction of a few of the plates.

The principal characteristics of the spectrum of the simple induction discharge at different pressures are shown in Figs. 1 and 2, Plate XIX, corresponding to pressures of about 10 and 1 mm respectively. The wave-lengths of the principal negative pole bands are indicated, and an iron comparison spectrum is also given. Alongside of Fig. 1, is a diagram of the vacuum tube, showing the corresponding appearance of different parts of the discharge. In Fig. 1 the first dark space extends less than a millimeter from the cathode, the second is nearly a centimeter long, and the negative bands barely stretch across it. The almost perfect symmetry of the glow is well shown. It is to be noted that all the positive pole bands appear at the cathode, and are about as intense as in the positive column. They extend faintly across the second dark space, as well as the first, so that these spaces are by no means absolutely dark. Sufficient exposure would always bring out all the positive bands throughout the dark spaces.

In Fig. 2 the first dark space is several millimeters long, while the second is driven up to the positive column by the negative glow; but the strong negative pole bands run across to the anode, with uniformly diminishing intensity. Here also the negative pole bands appear to be symmetrical on both sides of the cathode, while the positive bands are somewhat stronger toward the anode. This is probably due to the fact that the discharge was not strictly uni-directional, so that feeble positive alternated with strong negative discharges from *C*. Similar effects were observed on several plates at low pressures, but not at high pressures. Several striations of the positive column are shown, with marked variations in the intensity of the positive bands, but so little in that of the negative bands that it is suggested that the latter run through the positive column without any variations except a gradual decrease of intensity, the small differences observed being due to the underlying weak

positive bands. Similar effects were observed on several plates, and show that the negative glow is independent of the changes of potential gradient found in the striations and the second dark space. In the first dark space, however, the bands are somewhat weaker than they are at the beginning of the glow. It is interesting to note that the *F* line, which frequently appeared, and two strong lines which appear to be λ3962 and λ3944 the longest lines of aluminum, are strongest in the first dark space. These aluminum lines appeared on nearly all the plates, increasing in intensity as the pressure diminished, and extend, not the entire length of the negative glow, but only about as far as the "spluttering" of aluminum on the walls of the tube could be observed. This shows that the particles of metal detached from the electrode assist in the discharge, and can give a spectrum, although the contrary is sometimes assumed, and that this spectrum is probably due to aluminum in the atomic state, not in the form of cathode corpuscles, in which case the lines would extend throughout the negative glow.

II. EFFECTS DEPENDING UPON NATURE OF DISCHARGE.

It was found that some interesting changes resulted from altering the nature of the discharge, as in passing from the simple discharge to that with a spark-gap in the circuit and a condenser in parallel, or in adding self-induction to the above. Some of these effects, such as the transition from the line to the band spectrum, are well known, but others seem to have previously escaped observation.

These changes are described in detail below, with references to figures in some cases.

Pressure 100 mm (Plate XX, Fig. 3). — Simple discharge (*A*): The negative pole bands are faint and very short. The aluminum pair is absent. Self-induction (*B*): — There is a remarkable change in the appearance of the spectrum. The negative pole bands are strong across the entire field. The positive pole bands are very weak. The aluminum pair appears at both electrodes, and some faint aluminum lines at one electrode. Condenser (*C*): — The well-known line spectrum

appears, with some weak bands. The aluminum pair appears, but is not so strong as with self-induction. The appearance of the condenser discharge was dazzling white; that with self-induction was a light pink.

Pressure 40 mm (Fig. 4). — Simple discharge: As in previous case, except that the negative bands are longer. Self-induction (*A*): The negative pole bands are strong across entire field, but the contrast with the positive bands is not so strong as at 100 mm. The aluminum lines were weak. Condenser: Line spectrum as before. Tesla current (*B*): Very much like spectrum with self-induction, but the negative bands are relatively a little weaker. Note that this spectrum appears identical as far as relative intensities is concerned with the condenser spectrum (*B*) of Fig. 5.

Pressure 10 mm (Fig. 5). — Simple discharge: See Fig. 1, Plate XIX. Self-induction (*A*): Like (*A*), Fig 4, except that the positive bands are possibly relatively a little stronger. Condenser (*B*): The lines have changed to bands, but the negative bands are relatively not quite so intense as with self-induction. The spectrum is like that with the Tesla current at 40 mm. The condenser current was far more intense than the Tesla current; the self-induction current was of intermediate intensity. The relative intensities of the different discharges may be inferred from the fact that usually the times of exposure with condenser, self-induction, simple, and Tesla currents were about 10 minutes, 15 minutes, 20 minutes and 1 hour respectively. Where the relative differences in the spectra are small, perhaps the best estimate may be obtained by comparing the head of λ 3914 with the head of the neighboring positive band on the left. With self-induction in every case the former is more intense; with condenser or Tesla current they are about equal.

Pressure 2 mm (Fig. 6). — Appearance about as before, except that negative glow is much longer with simple discharge. Spectra with self-induction and with condenser are shown in (*A*) and (*B*). (*C*) and (*D*) will be described later.

Pressure 0.7 mm. — Simple discharge. — Negative bands run across to anode, and positive bands are very weak. Positive

PLATE XX.

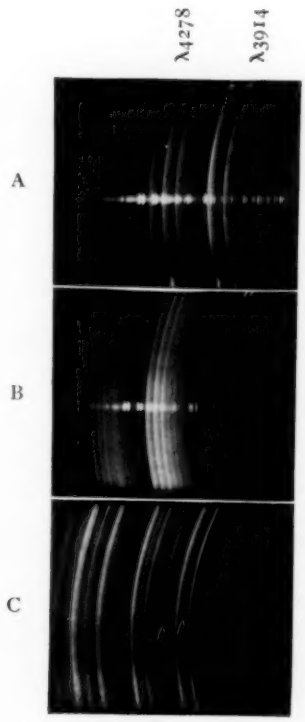


FIG. 3. P = 100 mm.

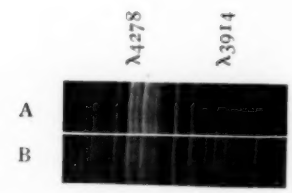


FIG. 4. P = 40.

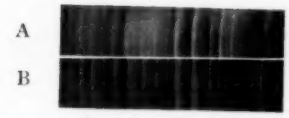


FIG. 5. P = 10.

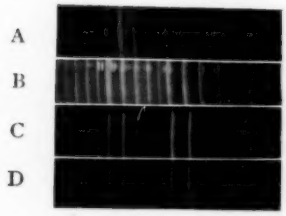


FIG. 6. P = 2.

column is about 4mm long. The spectra with self-induction and with condenser are hardly distinguishable, and the negative bands, while present throughout tube, are hardly so intense as one would expect from their appearance with the simple discharge and the low pressure. They by no means predominate over the positive bands.

With a slowly oscillating current through a vacuum tube, such as can be obtained when a condenser, without spark-gap, is in series with the tube (in which case the frequency is twice that of the primary break) both ends of the tube give the negative glow, which is limited to the ends. The question arises: why, with very rapid oscillatory discharges, do the negative bands appear from one end to the other? Goldstein[1] noted that with very intense discharges the negative bands appeared in all parts of the tube, and he seems to have associated this effect with the intensity of the discharge. We see, however, that the spectrum of the feeble Tesla discharge at 40mm is identical with that of the strong condenser discharge at 10mm. (At 40mm the condenser discharge gave a line spectrum, and at 10mm the tube was broken before a Tesla exposure could be made, so comparison at the same pressure was not made.) In all cases there was an enhancement of the negative bands by self-induction, although this effect became small at low pressures; but the self-induction discharge is weaker than that of the condenser. The electromotive intensity of the Tesla current is greater than that of the condenser, its intensity (energy) is less, and its oscillatory frequency is of the same order. The self-induction discharge is intermediate in energy, its frequency is much less than that of either condenser or Tesla discharge. It seems that we should look for the cause of the observed differences, not to electromotive intensity or energy (although they may take a part), but in altered frequency of the discharge. Just how this time element affects the problem is next to be considered.

A clue to the cause of the presence of the negative bands through the tube, and also to the effect of self-induction, is found in two important papers by Spottiswoode and Moulton.[2] They show that,

[1] *Berichte d. k. Akad. Berlin*, 1876 p. 281; *Wied. Ann.*, **15**, 280, 1882.

[2] *Phil. Trans.*, 1879, 1880.

in general, the time required for the discharge of negative electricity from an electrode is greater than that required by positive, and that in some cases discharges may take place from parts of the inner walls of the tube under the action of strong electrostatic stresses. Later J. J. Thomson[1] showed that the positive luminosity starts at the anode, travels at a finite rate toward the cathode, and even in a long tube will arrive at a point near the cathode before the negative glow. On account of the lag in the negative discharge, the walls of the tube, on which electricity is separated inductively, may assist the cathode in neutralizing the positive electricity, and this general discharge may account for the general presence of the negative bands when intense discharges are employed. If, however, the rate of oscillation is very rapid, as in the condenser discharge, the interval between two oscillations may be too short to allow complete discharge of the negative electricity—in other words, the discharge may be, as Spottiswoode and Moulton found in some cases, almost uni-polar, taking place only from the anode, and the negative bands will be weak. On introducing self-induction the oscillations become slower and a more complete discharge of negative electricity may result, thus enhancing the negative bands. The intensity or temperature of a discharge may determine the production of a line or band spectrum, but it seems at least possible from these considerations that the appearance of the negative bands throughout the tube is only an indirect effect of the intensity, depending directly upon the cathode rays emitted from the walls of the tube under the action of electrostatic stresses. It might be anticipated that the metallic screen with slit near the tube would magnify these effects, but the same results were obtained when a slit ruled on a developed photographic plate was substituted.

If this hypothesis be correct, the action of a cathode or X-ray tube with spark-gap and condenser in parallel should be stimulated by adding self-induction. It is probably known that this is the case, although previously unknown to the writer. A test substantiated this expectation; self-induction added to the cir-

[1] *Recent Researches in Electricity and Magnetism*, p. 116.

cuit of a cathode ray tube increased the fluorescence several times, although the spark-gap showed plainly that the intensity of the discharge was thereby diminished.

K. Wesendonck[1] showed that the walls of a vacuum tube seem to facilitate the negative discharge.

Another test was made by placing the electrodes previously used in a large glass bulb about 15 cm in diameter. The discharge through this tube was very unsteady except at pressures under 10 mm, so that it was difficult to get photographs at higher pressures. At about this pressure both the condenser and self-induction gave the continuous negative bands; but they were very feeble compared with those obtained with the small tube. At a pressure of about 2 mm the heads of the $\lambda 4278$ and $\lambda 3914$ bands can barely be detected in the spectrum of the condenser discharge (Fig. 6, *D*), but with self-induction they are seen faintly at the electrodes, while elsewhere there is not a trace of them to be seen (Fig. 6, *C*).

This is strong corroborative testimony, but is, of course, not absolutely conclusive as excluding the effects of intensity until we know how much the latter is modified by the size of the tube. With the large tube, however, the discharge confined itself within a limited space, and while not so intense as at the same pressures in the small tube, the difference in intensity did not seem sufficient to account for the difference in spectrum. In the large tube the discharge seemed more noisy and disruptive, just as though the cathode rays discharged from the walls of the smaller tube might have had some effect in facilitating the discharge. With both condenser and self-induction the large tube fluoresced very strongly, as though vigorous actions of some sort were going on at its surface.

All of these facts are suggestive, if not conclusive, and show that the effects of the walls of vacuum tubes cannot safely be neglected in the study of spectra.

It seems possible that the peculiar effects of self-induction noted by Hemsalech[2] may be accounted for in a similar way, not as a result of modified intensity of discharge or temperature,

[1] *Wied. Ann.*, 41, 473, 1890.

[2] G. HEMSALECH, *Thèse*, Paris, 1901.

but as dependent upon the time allowed for the discharge of negative electricity. Spottiswoode and Moulton showed that the time required for the discharge of "molecular streams" from the cathode was of the same order as that for the discharge of negative electricity. If these molecular streams consist of the particles which splutter from the cathode, the initial spark of a rapid oscillatory discharge must pass through air because there has been no time for sufficient metal to pass off; but by the time the second oscillation begins some metal has passed off and carries the discharge. When the oscillations are made slower by self-induction, there will be enough metal present from the beginning to carry the discharge. Why the self-induction brings out the negative-pole bands of air with some metallic electrodes is not so clear; but perhaps a difference in the time of discharge of molecular streams with different metals as compared with that of the discharge to air may account for it.

It seems likewise possible that some vacuum tube effects which have been held to suggest electrolysis may also depend upon the relative times required for negative electricity to discharge itself into different gases and metallic vapors. The spectrum of traces of hydrogen and of metallic vapors in vacuum tubes may appear stronger at the cathode simply because the discharge to them may take place more easily and more rapidly than to the gas, so that they can act as stepping-stones between the cathode and the latter. At the anode the converse may be true.

It seems obvious that this and other important questions regarding the division of the current in mixed gases, differences at the electrodes, and the effect of different forms of electric discharge can be most satisfactorily dealt with by photographing the spectrum of all parts of the tube simultaneously. An effort will be made to carry these preliminary results farther with improved methods which will allow accurate adjustment, greater dispersion, and an extension of the observations to the ultra-violet.

The conclusions suggested by this preliminary work may be summarized as follows:

1. The negative pole spectrum of nitrogen is due to cathode

rays. The intensity of the negative bands with simple discharge is dependent solely upon distance from the cathode, and is independent of changes of potential gradient in the tube.

2. The positive bands are present in the spectrum of all parts of the tube, but are of variable intensity, which seems to depend in large part upon the potential gradient.

3. The presence of the negative pole bands in the spectrum of all parts of a tube when strong discharges are used is due to the discharge of cathode rays from the walls of the tube.

4. The enhancement of the negative bands by self-induction is due to the slower rate of oscillation, permitting a more complete discharge of negative electricity, which requires more time than the positive.

UNIVERSITY OF CALIFORNIA,
March 1, 1903.

ON A NEW RELATIONSHIP BETWEEN ARC AND SPARK SPECTRA.[1]

By J. Hartmann.

In collaboration with Dr. Eberhard[2] I recently pointed out that in the spectrum of the arc under water the lines otherwise observed only in the spark spectrum, appear in the case of different metals—a phenomenon also previously noted by other observers with the arc burning in a hydrogen atmosphere. I have now succeeded in finding a way by which the arc spectrum can be transformed into the spark spectrum in atmospheric air also, hence without any alteration of the dielectric. I desire briefly to communicate in what follows these experiments, which give us a new insight into the processes involved in electric discharges.

My experiments were at first concerned with the spectrum of magnesium, which is of such great importance in astrophysics. As early as 1888 Liveing and Dewar[3] had pointed out that the line at λ 4481, which otherwise occurs only in the spark spectrum, appears also in the arc spectrum if this is made to pass between two magnesium rods, and not between carbon poles into which the metal was introduced, as was the general practice. I had photographed the spectrum of the arc between metallic poles several times, and was surprised that I always found only faint traces of the line λ 4481, while this had been obtained on the spectrograms published by Crew[4] in 1895, taken with the "rotating arc,"[5] as one of the strongest lines, and at least ten times as strong as the neighboring "arc line" λ 4352. Basquin[6]

[1] Translated from advance proofs, furnished by the author, of a paper to appear in the *Sitzungsberichte der K. Akad. der Wiss. zu Berlin.*

[2] Astrophysical Journal, **17**, 229–231, 1900. [3] *Proc. R. S.*, **44**, 241, 1888.

[4] *Normal Spectrum of the Magnesium Arc.* Evanston, 1895.

[5] Henry Crew and Robert Tatnall, "On a New Method for Mapping the Spectra of Metals," *Phil. Mag.* (5), **38**, 379, 1894.

[6] "The Spectrum of Hydrogen Given by the Metallic Arc of Tin, Copper, Silver," etc., Astrophysical Journal, **14**, 13, 1901.

also reached the conclusion that the line 4481 appears in the rotating arc, but not in the arc between stationary metallic poles in the air.

In the method of the rotating arc employed by Crew, numerous interruptions of the current occur, and we might suspect that the extra currents associated with the formation of the spark might have produced a spectrum similar to that of the spark, since the circuit contained coils of wire when the direct current from the dynamo was used. To exclude this possibility I have always used the current from a storage battery of 60 cells, and have avoided all coils of wire in the circuit, aside from a few turns of a resistance coil from which no self-induction could be feared. The observations described below were made on photographs taken with stellar spectrograph No. I of the Astrophysical Observatory.

In order first to determine whether the line at λ 4481 appears only at the instant of lighting or extinguishing the arc, or whether it appears only at definite positions in the arc, a photograph was made of the spectrum of the metallic arc when burning quietly, those two instants being excluded while the images of the electrodes were projected on the slit. The current was of about 6 ampères at a voltage of 120. This plate shows the line λ4481 to be actually present in the spectrum of the quiet metallic arc, but also that it appears principally at the electrodes, as in case of the spark discharge, while it is hardly visible at the center of the arc of about 8 mm length. But even close to the electrodes the intensity of the line was not great, certainly very much less than that of the line λ4352. If we denote with J the intensity of the spark line λ4481, that of the arc line λ4352 on the same plate being taken as unity, we may summarize the result of this plate as follows:

METALLIC ARC IN AIR 8 mm LONG, AT 120 VOLTS AND 6 AMPÈRES.

At the electrodes - - - - -	$J = 0.1$
At the center of the arc - - - -	$J = 0.01$

This experiment would therefore be insufficient to explain the high intensity ($J = 10$) of the line on Crew's plate, for even if it were desired to use light only from the immediate neighbor-

hood of the electrodes, the line at λ4481 would still appear decidedly fainter than the arc line λ4352. I then began experiments with different current strengths at a constant voltage of 120, since I suspected that the current strength might have an influence on the intensity of individual lines. I employed incandescent lamps for resistance in order to cut down the current sufficiently without introducing resistance coils.

Since the occurrence of the line in the quiet metallic arc was proven by the above-described experiment, I no longer projected the arc upon the slit and no longer excluded from the plate the instant of starting and extinguishing the arc. Hence J denotes the intensity of the line in the total light radiated by the arc. These experiments now gave the quite astonishing result that the 4481 line becomes the stronger as the current strength is lessened. Repeated photographs gave the following results:

METALLIC ARC IN AIR AT 120 VOLTS.

At 8 ampères	- - - - -	$J = 0.03$
6 "	- - - - -	0.05
3 "	- - - - - -	0.5
0.8 "	- - - - -	3
0.4 "	- - - - - -	10

These figures clearly show how the intensity of the spark line relatively to the arc line continuously increases with decreasing current strength; and indeed so regularly that it would be easy, for instance, to specify the current strength at which the two lines would appear of equal intensity; this would occur at about 2 ampères.

In view of the result of these experiments it would be difficult to maintain the assertion that the line λ4481 is an evidence of a very high temperature of the metallic vapors, for the development of heat is certainly not greater in the arc at 0.4 ampères than at 8 ampères with the same voltage. With the latter current strength the electrodes were so greatly heated as readily to melt, and the vaporization of the metal was so great that the poles could be separated by more than 10mm; while at 0.4 ampères the electrodes were entirely cool and the arc could not be lengthened beyond 0.5mm at most, and then it burned for

hardly more than a second, and had to be very frequently started up.

It might now perhaps be asserted that close to the electrodes the temperature of the vapor is so much higher than at other parts of the arc that, as a direct consequence of the small separation of the poles required by the low current, the *average* temperature of the whole arc was higher in the latter case than if the arc had a stronger current and greater separation of the poles, and could perhaps cool off more near its center. But were this assumption correct, then in the first-described arrangement of the experiment with the projection of the portion of the arc close to the pole, the intensity of λ4481 should have been correspondingly high—in fact, much higher than the intensity of the arc line λ4352. This, however, was not most remotely the case, since the intensity in that case also was only 0.1. There remains, therefore, nothing else to assume than that the conditions for the development of those molecular vibrations to which the line λ4481 corresponds were much more favorable in the small arc in spite of its lower, or at least certainly not higher, temperature than in the larger arc.

It cannot at present yet be stated with certainty what constitutes these "conditions," but we might hope to find an explanation of the observed phenomenon in the following two facts. As already stated, the small arc went out very frequently, and had to be started several hundred times during the exposure, which lasted for about half an hour on account of the small brightness of the point of light, so that only a comparatively short time of quiet burning followed each rekindling. The observed changes of intensity could be reasonably explained, if we assume that at the moment of kindling or of extinction another spectrum occurred in which the line λ4481 was strongly predominant. The correctness of this explanation could be determined by successive exposures of the arc with a rotating mirror or on moving films, which have recently been carried out in a very complete manner, for instance, by Crew and Baker.[1]

[1] "On the Thermal Development of the Spark Spectrum of Carbon," ASTROPHYSICAL JOURNAL, **16**, 61, 1902.

Should the explanation prove to be correct, it is to be noted that this introductory spark should by no means be confused with the commonly observed induction spark; with the precautions that I have described it can possess no elevated tension and temperature. We should rather conclude only that at the moment of the first passage of the electricity from one electrode to the other particles of metal are torn off which even at low temperature execute vibrations corresponding to the line λ4481.

The second fact which could be adduced in explaining the phenomena I have observed would make the line λ4481 appear, not as a high-temperature line, but even as one of low temperature, if such a designation were indeed at all permissible. According to an observation by Schenck,[1] which I was also able to confirm, the intensity of the line 4481 decreases in the *spark spectrum* if the electrodes are heated to the point of melting, so that the resistance in the spark gap is diminished by the active vaporization of the metal. I found further in another experiment that the intensity of this line decreases if the resistance in the dielectric is reduced by exhaustion. If we transfer this to the arc spectrum, we shall obtain a very good explanation of the phenomena in question. We may assume, according to Schenck's investigations, that the line λ4481 results from the vibrations of particles highly charged with electricity, and therefore it can appear only of reduced intensity, if at all, if such a charge is in any way prevented. Now, as soon as the electrodes are heated by the stronger current there occurs a vigorous vaporizing of the metal, the conductivity in the arc becomes greater, and the separate particles take on only very slight charges, so that the vibrations corresponding to the line λ4481 must always become weaker with increasing current strength.

As I have already remarked, the magnesium electrodes very soon melted when only moderate currents were used, and thus they immediately set a limit to further heating and vaporization. When using metallic electrodes the experimenter is therefore compelled by the purely incidental process of melting to main-

[1] "Some Properties of the Electric Spark and its Spectrum," ASTROPHYSICAL JOURNAL, 14, 116, 1901.

tain the poles in a cool condition in some way, whether by artificial cooling, by the employment of a very small current, by the frequent interruption of the current, or by the continual introduction of new and cold parts of the metal into the arc. Crew employed the latter process in his rotating arc, and in consequence obtained so powerful a 4481 line, as above stated. The vaporization was similarly very slight in the small arc with 0.4 ampères, and the line accordingly was very strong, becoming more and more faint with the increasing vaporization of the electrodes.

The absence of this line from the carbon arc can be very simply explained in this way. If magnesium is introduced into the arc burning between carbon poles, the above mentioned limit is no longer set for the greater heating and vaporization of the metal, and the arc becomes a very good conductor, as might already be inferred from its greater length, whereby, in accordance with what has been said, the disappearance of the arc line is occasioned.

The ingenious experiments of Basquin[1] who simultaneously caused the arc and the spark to pass between the same electrodes, are also in full agreement with the view here developed. When a second spark gap was introduced into the circuit of the spark discharge, there appeared in the arc simultaneously the arc and the spark lines. If, however, the second spark gap was made very short, the spark lines disappeared completely in the arc, although the spark discharges passed through the arc as before. If the arc current was now interrupted, there was a duration of about a second before the spark began to pass in the ordinary noisy manner, and then the spark spectrum also first appeared. This experiment proved, first, that in the condition of the vapors prevailing in the electric arc those molecular vibrations are also possible to which the spark lines correspond; and second, that these vapors, even up to a second after the extinction of the arc, conduct so well that a high-tension current can pass between the electrodes without forming sparks, therefore without producing the spark lines.

[1] *Loc. cit.*, p. 15.

I would also revert here to the experiments which I made, in common with Dr. Eberhard,[1] using zinc electrodes. We succeeded, in the first place, in showing that the spark spectrum of this metal approaches the arc spectrum on artificial heating and vaporization of the zinc electrodes, in a manner analogous to the process observed by Schenck. But *per contra*, we did *not* succeed at that time with the reverse experiment, namely, of transforming the arc spectrum into the spark spectrum by cooling the electrodes with liquid air. This failure may, however, be simply explained if a very high temperature still prevails at the points of the greatly cooled electrodes; we might infer that this was the case from the fact that the arc could be drawn out to a length of several millimeters without going out. It is possible that a photograph would have shown a slight alteration in the relative intensity of the arc and spark lines, but on account of its difficulty this experiment was not made. But we did succeed in obtaining very distinctly the two zinc spark lines at $\lambda 4912$ and $\lambda 4925$ on reducing the current to 0.5 ampères and by using very large poles which conducted the heat well, although we had found hardly a trace of these lines in the arc with a current of about 6 ampères.

I have obtained a further confirmation of my observation on magnesium in the spectrum of bismuth. The very strong spark line at $\lambda 4260$, which does not appear in the carbon arc, appears in the arc between metallic poles only slightly fainter than the neighboring arc lines at $\lambda 4254$ with 6 ampères current; but at 0.3 ampères it still appears very distinctly, while the arc line has wholly disappeared.

With lead electrodes in the arc I succeeded even at 6 ampères in obtaining the two principal spark lines, at $\lambda 4245$ and $\lambda 4387$, although they do not appear at all in the carbon arc. In order to test still further whether the small amount of vapor between the electrodes is in fact a sufficient cause for the appearance of spark lines in the arc, I made the experiment with this metal in such a manner that the one electrode consisted of melted lead, heated to active incandescence and vaporization. When the

[1] *Loc. cit.*, p. 41.

same current of six ampères was passed across from this vaporizing mass of metal to a cold lead pole there no longer appeared any trace of the two spark lines in the arc spectrum. This observation accordingly also furnished a proof of the correctness of the view expressed above.

Since we might be inclined to assume that a high voltage is necessary for the production of the vibrations corresponding to the spark lines, which is indeed always present in the ordinary spark discharges, I made the further attempt of also bringing out the spark lines, which are under ordinary conditions lacking in the arc, merely by diminishing the tension while the current strength remained constant. This experiment was also completely successful. For this I again used magnesium poles, and employed the current of 20 volts and 4 ampères from ten storage cells. The development of heat was so slight that there was no longer any appreciable vaporization of the metal, whence the formation of an actual arc was excluded. The very small introductory spark, certainly hardly 0.1 mm long, which appeared every time the poles were separated from electrical contact, showed the line 4481 decidedly stronger than did the longer arc, in spite of the fact that it surely had no higher temperature than the arc with equal current strength and sixfold greater voltage. My photograph gave

at 20 volts and 4 ampères - - - $J = 10$

while from the figures above we get

at 120 volts and 4 ampères - . - - $J = 0.3$

Although the consumption of energy is in this case reduced to one-sixth, the relative intensity of the spark line nevertheless has risen about thirtyfold.

All of my observations which I have here described, as well as the results of numerous other observers, of which I have mentioned only a few above, indicate that the spark lines do not correspond to a thermal radiation but rather to electroluminescence. This idea is not new, but was expressed in the following very precise manner in 1888 by Liveing and Dewar,[1] when they discovered the occurrence of the $\lambda 4481$ line in the

[1] *Proc. R. S.*, **44**, 241–242, 1888.

arc spectrum: "The observations, however, render doubtful the correctness of the received opinion that the temperature of the spark discharge is much higher than that of the arc. Heat, however, is not the only form of energy which may give rise to vibrations, and it is probable that the energy of the electric discharge as well as that due to chemical change, may directly impart to the matter affected vibrations which are more intense than the temperature alone would produce."

This clearly expressed view unfortunately received too little attention at the time, and in later years hypotheses have been founded on the wholly unproven assumption, rendered dubious by the above remark by Liveing and Dewar, that the spectrum of an incandescent gas is a function of only the *one* variable, "temperature," which hypotheses should render possible a direct conclusion as to the temperature of the luminous gas from the occurrence of individual lines. This would have been not without significance, especially for astrophysical research, although there exist other methods, free from objection, for determining the temperature of celestial bodies; but, as I have shown, such a conclusion is not permissible, at least in so far as the magnesium lines $\lambda 4481$ and $\lambda 4352$ are in question, since so far a proof is entirely lacking that the line $\lambda 4481$ always corresponds to a higher *temperature* than the line $\lambda 4352$. We should be inclined from my experiments described above to reach the contrary conclusion, but such a conclusion is also unpermissible, since, as is confirmed by all previous observations, the production of the spark lines probably is not related to the temperature. I do not regard it to be impossible that those molecular vibrations which cause the occurrence of the spark lines, whose excitation has hitherto been solely possible by the use of electric discharges, may occur exclusively by the introduction of energy in the form of heat; but for the correctness of any such assumption no laboratory demonstration can yet be adduced.

In view of what has been said, it may well be difficult further to maintain the hypothesis advanced by Scheiner[1] in 1894.

[1] "Die Temperatur an der Oberfläche der Fixsterne und der Sonne, verglichen mit derjenigen irdischer Wärmequellen," *Sitzungsberichte der k. Akad. der Wiss. zu Berlin*, 1894, p. 257.

Inasmuch as the line λ4481 appears very strong in the spectra of numerous stars belonging to Vogel's first type, while λ4352 is very faint or not present, Scheiner reached the conclusion that on these stars the temperature of the absorbing layer was approximately that of the electric spark, while the temperature of the stars of the second and third type, in whose spectrum the line λ4352 more strongly occurs, the temperature approximated more closely that of the arc. The above demonstration that the intensity ratio of the two lines denoted by *J* by no means increases with rising temperature, indeed probably stands in no direct relation to the temperature, causes these conclusions to lose their foundation as well as their force.

But there is still a further circumstance to be considered. As has been shown by the observations of Crew,[1] Basquin,[2] and Porter,[3] as well as by the above-mentioned investigation by Eberhard and myself, the dielectric has a great influence on the spectrum of electrical discharges. Now since all stars of the first spectral type are characterized by a great preponderance of hydrogen in their atmospheres, it would seem that only observations which have been made in an atmosphere of hydrogen should be adduced in interpreting the spectra of those stars. It was already known from the publications of the first-named observers that the hydrogen atmosphere so favored the appearance of the line 4481 that it also came out very strong in the arc, and I therefore suspected that my experiments in a hydrogen atmosphere discussed above would furnish still larger values of *J*. This expectation was most fully confirmed, for a photograph of the arc burning in a hydrogen atmosphere at 120 volts and 0.3 ampères showed *no trace of the arc line*, while the line 4481 came out perfectly sharp and as the strongest line of the whole spectrum; in addition to this line the spectrum further contained only the three lines λ3830, λ3832, and λ3838, and

[1] "On the Arc Spectra of Some Metals, as Influenced by an Atmosphere of Hydrogen," ASTROPHYSICAL JOURNAL, **12**, 167, 1900.

[2] *Loc. cit.*, p. 1.

[3] "The Influence of Atmospheres of Nitrogen and Hydrogen on the Arc Spectra of Iron, Zinc, Magnesium, and Tin, Compared with the Influence of an Atmosphere of Ammonia," ASTROPHYSICAL JOURNAL, **15**, 274, 1902.

very faintly the *b* group. Accordingly the strength of the 4481 line and the absence of the arc lines of magnesium in stellar spectra of the first type can no longer be regarded as striking. It would seem to be more important to give some attention to the occurrence of the two above-mentioned magnesium triplets. These are the most permanent lines in the portion of spectrum I have investigated, occurring with every form of luminosity, even in the spectrum of burning magnesium, and we may well assume that the corresponding molecular vibrations are of a purely thermal origin. Nevertheless, they do not occur in many star spectra which contain a strong 4481 line, as Keeler[1] has already remarked of the *b* group.

The last-mentioned spectrum photograph shows a further peculiar appearance which I should not leave unmentioned. While those two triplets and the line 4481 are all that remain of the whole magnesium spectrum, there further appear on the plate as impurities of the metal, the three calcium lines λ 3934, λ 3969, and λ 4227, as well as the lead line λ 4058—all of them lines which, like the triplets, are easily reversible and make their appearance at low temperatures. Just as the method of oscillating discharges first employed by Schuster and Hemsalech, which permits a gradual transition from the spark spectrum to the arc spectrum, so also the method of the "small arc" described here, which represents the inverse transition from the arc to the spark spectrum, should be suitable for furthering the discovery of related groups of spectral lines, and hence for the study of the processes of luminosity.

ASTROPHYSICAL OBSERVATORY,
Potsdam, February 26, 1903.

[1] "The Magnesium Spectrum as an Index to the Temperature of the Stars." *Astronomy and Astro-Physics*, 13, 660, 1894.

DISCUSSION OF A QUESTIONABLE TYPE OF TEMPORARY STARS.

By J. G. HAGEN, S. J.

IT is understood that by a "temporary star" is meant a star which has been seen to vary in brightness a single time, although this variation may have extended over months or years, and may have been composed of fluctuations of various amplitudes. If two or more variations of this kind have been observed, the star is usually called a periodic variable, regular or irregular.

When the outburst of a temporary star was so short in duration that it was seen by one observer only, without independent confirmation by another, the record has generally been received with suspicion and accepted with explicit reserve. This is the case with two stars that have found a place in the catalogues of variable stars. There are three more instances of an earlier date, one of which has never been published. A simultaneous inspection of these five cases and of the authorities on which they rest will probably remove all reasonable doubt as to the existence of short variations of this kind. The astrographic charts, which give three successive exposures to the stars, may reveal some more variations of this character by abnormal intensities in the points of the small stellar triangles.

The five temporary variations of short duration will be related in the inverse order of time, beginning with the most recent. They can very conveniently be put in three groups.

I. TWO KNOWN TEMPORARY STARS OF SHORT VARIATION.

1. The star *U Scorpii* is No. 73 in *Schönfeld* I, No. 87 in *Sch.* II, and No. 5860 in *Chandler* I-II. When Pogson observed its variation in 1863, he was government astronomer in Madras, and had a ten years' experience on variable star work. He saw the star decrease from 9th mag. to invisibility in twelve days. The star has never been recognized by anyone else, but is called by Pogson a well-assured, rapidly changing star. The chance for

a second observer to see the variation was probably confined to one or two days. When the star was below mag. 10 it would have been very difficult to identify it without a chart.

2. The other star is *T Bootis*, No. 58 in *Sch.* I, No. 70 in *Sch.* II, and No. 5097 in *Ch.* It is almost of exactly the same character as the former, and was observed in England only three years previously, in 1860, by Pogson's brother-in-law, J. Baxendell. On April 9 it was of magnitude 9¾, on April 11 of mag. 10, on April 20 of mag. 12.8, and on April 23 it was invisible (in Baxendell's own scale). The variation was observed during twelve days, but the chance for independent confirmation could hardly have extended over more than two days.

II. TWO INSTANTANEOUS VARIATIONS OF LIGHT.

1. An instantaneous fluctuation of light was observed by Pogson in the star *U Geminorum* on March 26, 1856, while he was preparing a chart for this variable. Pogson was then assistant astronomer at the Radcliffe Observatory in Oxford, where he had commenced working on his intended atlas of variable stars three years previously. His observation has lately been published in the *Astronomical Journal* (**22**, 127, 1902), from which we quote what is essential: "The variable subject to strange fluctuations at intervals of 6 to 15 seconds. . . . . when the adjacent stars were quite steady. At times it surpassed the star 8.9, at others it quite vanished. . . . . Watched it for half an hour, with powers 54, 65 and 95 on the equatorial." The comparison star 8.9 is probably No. 5 in the *Atlas Stellarum Variabilium* (Series II, 2815). The range of these fluctuations seem to have been the same as that of the periodic changes of this variable.

2. A similar fluctuation of light was observed by Heis in the star ζ *Lyrae* on September 26, 1850. Heis observed the variable star β *Lyrae* from 1841 to 1868, and used as comparison stars, among others, ϵ and ζ *Lyrae*. Each of these has the magnitude 4½, but appears double to the naked eye on very clear nights. Heis found the relative brightness of these two comparison stars slightly changeable. On the date mentioned the observing book (which will soon appear in print) has the following note: ζ *Lyrae*

became for a *moment very bright*, and then again faint" ("*ζ Lyrae* wurde einen *Moment sehr hell* und hierauf wieder dunkel").

The star probably did not reach the brightness of the neighboring first-magnitude star *α Lyrae*, else Heis would hardly have omitted the comparison. The time of the fluctuation must have been too short to be measured, because Heis was in the habit of recording the time in whatever he observed.

The short note deserves the more confidence, as Heis had been familiar with this comparison star for nine years; further, as his eyes saw the stars as distinct points without false rays (see E. Heis, *De Magnitudine relativa*, etc. Monasterii, 1852, page 4), and finally as his observations of variable stars show a rare precision in estimating steps.

III. AN OLD OBSERVATION OF CHRISTOPH SCHEINER, S.J., IN 1612.

This observation is described by Scheiner in his second letter to Welser, dated April 14, 1612, and printed in his book: *De Maculis solaribus*, etc. Augustae Vindelicorum, 1612. As this book is rare, Winnecke republished the Latin text in the *V.J.S.* (13, 283–288, 1878).

1. What Scheiner *observed* may be summarized as follows: He gives nine drawings of the field of view in his telescope, which he calls the best he ever saw for observing *Jupiter's* satellites. They were made when the sky was very clear and without moonlight. They give the relative positions of the planet *Jupiter* and its satellites, on March 29, 30, 31; April 1, 3, 5, 6, 7, 8. In the same field a star denoted by the letter E is drawn, about 6′ south of the planet. Scheiner's argument that this star had a motion of its own is evidently not conclusive. It is based on eye-estimates only of its motion relative to the planet, which became stationary a few days later, about April 10. Scheiner was prejudiced on this point by the hope of discovering a fifth satellite of *Jupiter*.

What he says about the light of this star is of more importance. The first drawing, on March 29, shows nothing of the star in question. On March 30 Scheiner saw it for the first time (*primus illius contuitus mihi obtigit*), and, as is usual with tempo-

rary stars, at once very bright and large (*lucentissimam et maximam*), like any of *Jupiter's* satellites (*quanta . . . . hactenus quaevis conspecta est stella Jovialis*), and, as he adds a little later, much brighter and larger than the fainter satellites, which he describes as much inferior in light and size (*lucis et corporis multo quam potiebatur stella E minoris*). During the following days it fell below the fainter satellites, until, on April 8, it was seen with great difficulty (*ægerrime*) in a very clear sky. After that date it was never seen again, although carefully looked for under favorable conditions. Scheiner had several smaller telescopes with which the star was seen at its greatest brilliancy. He also showed the star to his friends.

2. *The identification* of this star was made by Winnecke.[1] With the help of Küstner he found from Leverrier's tables of the Sun and *Jupiter* that the position of Scheiner's star was identical with the place of *B.D.* + 15°.2083, $8^{m}.5$, within the residuals 0^{s}, 1′.4. This star is not a periodic variable. It has been constantly recorded as of magnitude 7–8 or 8 or 8.5, by Lalande (1796), Weisse (1825), Struve (1826), Preuss (1833), in the *B.D.* and the *H.P.* Winnecke himself watched it for seventeen years. Among the thirteen observations in the *H.P.* (Vol. 24, page 220) there is one large residual from the mean magnitude 8.0, amounting to +2.4, which would make the star $10^{m}.4$; yet the series 991, in which this residual occurs, has the accompanying remark: "thin clouds noticed in various parts of the sky" Vol. 23, Part I, page 39). Clouds will explain any positive residual, and also any negative residual, if the pole star, which served as comparison star for the meridian photometer, was covered by them.

3. For the *range* of the light variations we can deduce from Scheiner's description an approximate upper limit. The literature on the photometry of *Jupiter's* satellites is put together in Dr. Müller's *Photometrie der Gestirne*, pp. 385–393. The mean

[1] Winnecke makes no reference to the possibility that Scheiner's star might have been a planet, stationary near *Jupiter*. *Uranus* and *Vesta* reach the brightness of *Jupiter's* satellites, but would hardly show variations as those described. We leave this question open and base our further discussion on Winnecke's opinion that the star in question was a fixed star.

results of Engelmann's, Pickering's, and Spitta's photometric measures for the faintest and brightest satellites are the following: satellite IV: $6^m.5$, and satellite III: $5^m.5$, the other two ranging between. These figures hold for "mean opposition," *i. e.*, for the opposition of Earth and *Jupiter* at their mean distances, and for the mean albedo or reflecting power of the satellites. The reduction to quadrature, at which Scheiner observed, would diminish these magnitudes only $0^m.1$ or $0^m.2$, as may be concluded from Engelmann's reductions of Dr. Auwers' visual observations (*Helligkeitsverhältnisse der Jupiterstrabanten*, Leipzig, 1871, page 67), while the varying albedo may change these figures by $\pm 0^m.5$ (Engelmann, *loc. cit.*, page 69).

If we now remember that Scheiner calls his star E as bright as any satellite, and much brighter than the fainter satellites, we are safe in saying that his star had reached the sixth magnitude. In ten days it faded away to invisibility. This limit, in a telescope which was considered good and showed the fainter satellites well, should be at least as low as eighth magnitude, the normal brightness of star E. What the lower limit of the fluctuation actually was cannot be gathered from the data on hand.

Winnecke was familiar with Scheiner's writings and judges him as "thoroughly trustworthy in communicating what he had seen."

In conclusion these five instances seem to show that short variations in the light of stars, although noticed by only one observer, cannot be rejected when assured by good authority. Should Heis' remark on ζ *Lyrae* be considered too short or too casual to inspire full confidence, it seems that Scheiner's star in the constellation *Leo* has as much claim for enlistment among the temporary stars as *U Scorpii* and *T Bootis*. The star *U Geminorum* will always remain among the periodic stars, but its extraordinary fluctuation in 1856 should be borne in mind.

GEORGETOWN COLLEGE OBSERVATORY,
February 1903.

ON THE EFFECT OF CIRCUIT CONDITIONS UPON THE WAVE-LENGTHS OF SPARK LINES.

By NORTON A. KENT.

IN the summer of 1901 Professor Charles E. St. John, of Oberlin college, and the writer of this article, at the suggestion of Professor Hale, undertook to verify certain results obtained by Haschek[1] in regard to the relative position of the arc and spark lines of titanium.

Haschek had found that in some cases the displacement of spark lines toward the red from the position of the corresponding arc lines exceeded 0.1 tenth-meter, *e.g.*, 0.13 for *Ti* λ 3900.68. These were unusually large displacements.

After continuing the investigation alone for a short time[2] the writer was obliged to defer its completion to take part in a more important study (that of the spectrum of the electric discharge under liquids), and only recently has it been possible to return to the former subject.

APPARATUS USED.

The apparatus used was, in its general features, the same as that employed in the investigation of the spectrum of the electric discharge in liquids, and a description of the same will appear in the *Publications of the Yerkes Observatory* soon to be issued. For the present purpose a brief description will suffice.

A 5-horse-power motor drove a 3.3 kilowatt alternator (125 cycles per second, potential 110 volts, current 30 ampères), which fed a 1 kilowatt Lakon transformer. An adjustable condenser gave a capacity of from 0.0066 to 0.0560 microfarads. The arc and spark apparatus were set upon the circumference of a circle at the center of which was a plane silver-on-glass mirror, capable of being rotated about a vertical axis. The light could then be thrown from either piece of apparatus to a concave

[1] ASTROPHYSICAL JOURNAL, **14**, 181, 1901.

[2] *Ibid.*, **14**, 201, 1901.

mirror fitted with slow-motion screws which gave motions about horizontal and vertical diameters. From this latter mirror the light passed to the slit of the spectroscope — Rowland mount: radius of curvature of grating 10 feet; 15,000 lines per inch. The first spectrum alone was used; the dispersion was 5.63 t. m. per mm. The arc (direct current) was so arranged that after contact the carbons could be moved apart to a stop; this gave an arc of constant length. A current of 18 ampères was used in all cases. Before every exposure a small piece of metal, several milligrams in weight, was placed in a shallow hole in the lower carbon which formed the positive pole of the arc. These precautions were taken to avoid any possible change in the position or intensity of the standard lines of the comparison spectrum. Suitable shutters made possible the method of double exposure of the comparison spectrum. The arc was exposed for ½ second; then the spark for various lengths of time; then the arc again for ½ second, this third exposure being superimposed upon the first.

It will be noticed that the mirror method — suggested by Professor Hale — furnishes an easy means of avoiding the possibility of any false shifts due to unequal illumination of the grating. The short time of exposure employed for the arc might introduce such shifts unless all parts of the beam were exposed an equal time. For this reason, and also to facilitate obtaining arc spectra of the same intensity upon every plate, the following arrangement was used: a camera shutter, set less than an inch in front of the slit and operated pneumatically by a long tube and bulb, was fitted with a horizontal rectangular window. This window was so arranged that when the shutter was set the slit of the spectroscope was covered. When the bulb was pressed the beam was disengaged from the left side, and subsequently covered from the left side. Then the shutter automatically returned to its former position, repeating the above process in the reverse direction. Thus each of the four sets of exposures of ¼ second duration was complete in itself. As previously stated, the shutter was close to the slit, and on this account as well it seemed improbable that any error due to unequal illumination of the

grating would enter. The device worked most satisfactorily. The arc was thrown upon the shutter by setting the plane mirror properly and making final adjustments (always small) with the concave mirror. During this procedure the image was viewed with a telescope. Then the bulb was pressed and the exposure made.

The spark terminals were formed of pieces of titanium carbide or "cast titanium," 85 per cent. *Ti* and 15 per cent. carbon, purchased of Eimer & Amend, of New York. The shape of the terminals was not regular; but rough edges were presented to each other and the pieces shifted often to obtain new edges. It is to be regretted that time did not permit greater care in this respect, for it is well known that the form of the surface alters the potential of discharge, and this *may* affect the position of the line. Still it may be stated that the results show no errors which can be traced directly to this cause.

The displacements were measured with a Zeiss comparator of double microscope pattern, under a magnification of about eight diameters. Double parallel wires were found to give most accordant results. The plates were placed violet left and four settings were made on the comparison, or arc spectrum with three on the internal or spark spectrum; then the same set of measurements was repeated with the plate placed violet right.

RESULTS.

The results of the investigation are given in Tables I to IV. Table I shows the agreement between different plates, those in each group of two or three plates being taken under similar conditions as far as known, and the groups differing among themselves by reason of change of spark-length, capacity, etc. The average deviation from the mean of the measurements made upon the individual plates of the different groups is 0.005 tenth-meter, and the average deviation from the mean of the measurements of the four lines on the same plate (chosen at random) is under 0.003 tenth-meter.

Table II covers the results of six short series, upon which series the following brief remarks may be made:

A. *Changing the length of the primary or main gap*[1] apparently causes a change in the position of the spark line. The spark was vertical and its length was varied from 1 to 20 mm. The slit of the spectroscope was cut down to 6 mm; the concave mirror was so mounted that it gave an image 2.4 times as large as the source. In the three cases, then, the images were 2.4, 24, and 42 mm in length. Therefore the whole image of only the shortest spark fell upon the slit. With the 10 and 20 mm sparks the central 2.5 mm were used. This point will be discussed later. In Plates 11 and 12 a strong air-current was directed upon the spark by an electric fan—this to produce greater disruptiveness in the discharge. It may appear that the true series should be composed of Plates 3 and 4, 13 and 14, and 1 and 2; for in none of these was the fan used. But it may be well to remark that in 3 and 4, and 1 and 2, the spark was highly disruptive, in 13 and 14 it was not. (At this seemingly critical spark length it so much resembled the uncondensed spark that the exposure time had to be increased to 4 minutes, from 15 seconds in 1 and 2.) Therefore 11 and 12 may well lay claim to the right of being substituted for 13 and 14. *Probably* the fan will increase the displacement in all cases in which the spark is not inherently disruptive.

B. The work upon the spectrum of the spark under liquids (carried on in conjunction with Professor Hale), in which an *auxiliary air gap* was placed in the discharge circuit of the condenser in series with the liquid gap to produce sufficient disruption of discharge, at once suggested the trial of the effect of a second air gap in this case also. The results in the two cases, spark under water and spark in air, are identical as far as displacement is concerned: the introduction, or an increase in length, of the secondary gap produces an increase in displacement. The fan forced a current of air against both gaps.

C. *Increase of capacity* over the range employed seems to produce a small increase in displacement. For values of plates of the condenser in meters and microfarads see Table III.

[1] The difference between primary and secondary gaps will be made evident in section B.

D. *Introduction of self-induction*, even as small an amount as 0.000426 henries, into the discharge circuit of the condenser produces a great change: under such conditions the spark lines are more nearly coincident with the arc lines.

E. *Introduction of impedance*, of considerable but unknown amount[1] into the primary circuit of the transformer, has some influence on the position of the lines.

F. *Introduction of resistance* into the exciting circuit of the alternator, in addition to that of the field coils themselves, causes a decrease in displacement. Whether this change will always be in this direction—increased resistance, decreased displacement—is an open question. For certain reasons, which cannot be discussed here, but will be made evident in the *Publications of the Yerkes Observatory*, the writer is led to believe that under some conditions an increase of resistance may cause an increased displacement.

The effects of five[2] of the six sets of changes have their exact parallel in the water spark, and, indeed, the attempt to obtain such effects was suggested by the results obtained in that investigation. This collateral evidence goes far to compensate for the meagerness of data here presented. Moreover, in the spark in air at high pressure (210 pounds), introduction of self-induction decreased the displacement.[3]

It was stated above that in the primary spark-gap series only a 2.5mm central section of the longer gaps was used. It seemed advisable to study further the 20mm spark. Therefore the terminals were turned into a horizontal position, and a series of plates taken as shown in Table IV, to which the last portion (G) of Table I is preliminary.

The difference between the displacements given by plates 34 and 35, also by 36 and 37, Table I, is well accounted for by the fact that it was difficult to expose identically the same portions of

[1] Impedance coil: seven sections connected in parallel, each of 150 turns of No. 16 B. & S. copper wire; internal diameter of coil, 6.3cm; external diameter, 9.4 cm; total length of coil, 17 cm; soft iron wire core; closed magnetic circuit.

[2] In the water-spark investigation the effect of impedance was not tried.

[3] ASTROPHYSICAL JOURNAL, 17, 157, 1903.

the spark. It is perfectly evident, however, that a large difference exists between the displacement given by that part of the spark which is near the terminals and that which lies between them. From plates 36, 37, 38, and 39 it appears that there is little difference between the positions of lines given by the central portions of either long or short gaps. But no special stress should be put upon this point, because of the difficulty of placing upon the slit the central portions of either long or short gaps.

Attention should be called to the fact that plates 15, 16, and 28 do not give results which are in absolute accord with the primary spark-gap series. Nor do 36 and 37 agree well with 3 and 4. In the writer's opinion, this should not count against an acceptance of the results as accurate and of the effects as true, because (1) the plates cited were not taken upon the same day nor upon succeeding days (it is possible that a change in atmospheric conditions alters the positions of the lines); and (2) the shape of the terminals may not have been the same.

GENERAL DISCUSSION OF RESULTS.

Such large displacements as Haschek gives have not presented themselves. He used a capacity of 625 meters or 0.0694 microfarads. The maximum capacity here employed was 504 meters or 0.0560 microfarads. By referring to Mohler's table, given in his article on "Pressure in the Spark,"[1] it will be seen

TABLE I.

Relative positions of spark and arc lines observed under various modifications of the conditions of the spark circuit.

Displacement of spark lines toward red from position of arc lines given in tenth-meters. M = mean displacement.

A. EFFECT OF CHANGE IN LENGTH OF PRIMARY SPARK-GAP.

Line	Displacements for Separate Plates, with Means											
	3	4	M	13	14	M	11	12	M	1	2	M
3900.68	+.003	+.004	+.004	+.012	+.021	+.017	+.011	+.012	+.012	+.030	+.039	+.034
04.95	−.002	−.006	−.004	−.001	−.005	−.003	.....	+.010	+.010	+.011	+.034	+.022
13.58	+.009	−.001	+.004	+.011	+.009	+.010	+.007	+.013	+.010	+.032	+.044	+.038
98.77	+.003	−.011	−.004	−.009	−.018	−.014	.....	+.007	+.007	+.015	+.033	+.024

[1] Astrophysical Journal, 10, 204, 1899.

TABLE I.—*Continued.*

B. EFFECT OF CHANGE IN LENGTH OF SECONDARY SPARK GAP.

Line	Displacements for Separate Plates, with Means									
	15	16	28	M	17	19	M	20	21	M
3900.68.....	+.010	+.014	+.017	+.014	+.028	+.026	+.027	+.044	+.037	+.041
04.95.....	−.010	−.012	+.003	−.006	−.003	−.005	−.004	+.019	+.027	+.023
13.58.....	+.007	+.007	+.018	+.011	+.025	+.037	+.031	+.041	+.043	+.042
98.77.....	−.007	−.012	+.010	−.003	.....	+.009	+.009	+.023	+.027	+.025

C. EFFECT OF CHANGE OF CAPACITY.

Line	Displacements for Separate Plates, with Means												
	1	2	M	9	10	M	7	8	M.	4a	5	6	M
3900.68....	+.030	+.039	+.034	+.030	+.042	+.036	+.040	+.041	+.040	+.050	+.043	+.036	+.043
04.95....	+.011	+.034	+.022	.....	.....	.....	.....	.....	.....	+.038	+.022	+.031	+.027
13.58....	+.032	+.044	+.038	+.034	+.043	+.038	+.034	+.049	+.042	+.054	+.040	+.030	+.041
98.77 ..	+.015	+.033	+.024	.....	.....	.....	.....	.....	.....	.....	+.034	+.025	+.030

D. EFFECT OF INTRODUCTION OF SELF-INDUCTION.

E. EFFECT OF INTRODUCTION OF IMPEDANCE.

Line	Displacements for Separate Plates, with Means												
	23	29	M	4a	5	6	M	26	27	M	1	2	M
3900.68.....	+.008	+.012	+.010	+.050	+.043	+.036	+.043	+.036	+.025	+.031	+.030	+.039	+.034
04.95.....	−.010	+.003	−.004	+.038	+.022	+.031	+.027	+.008	+.005	+.007	+.011	+.034	+.022
13.58.....	−.010	+.014	+.002	+.054	+.040	+.030	+.041	+.026	+.018	+.022	+.032	+.044	+.038
98.77.....	−.002	+.001	−.002	.....	+.034	+.025	+.030	−.001	−.001	−.001	+.015	+.033	+.024

F. EFFECT OF CHANGE OF RESISTANCE IN FIELD CIRCUIT OF ALTERNATOR.

Line	Displacements for Separate Plates, with Means					
	24	25	M	1	2	M
3900.68.....	+.027	+.031	+.029	+.030	+.039	+.034
04.95.....	+.000	−.002	−.001	+.011	+.034	+.022
13.58.....	+.008	+.025	+.017	+.032	+.044	+.038
98.77.....	−.004	+.010	+.003	+.015	+.033	+.024

G. EFFECT OF USING DIFFERENT PARTS OF SPARK, AND SPARKS OF DIFFERENT LENGTH, AS SOURCES OF LIGHT.

Line	Displacements for Separate Plates, with Means								
	34	35	M	36	37	M	38	39	M
3900.68.....	.....	+.058	+.058	+.026	+.019	+.023	+.029	+.022	+.026
04.95.....	+.017	+.023	+.020	+.021	+.007	+.014	.....	.....	.....
13.58.....	+.039	+.051	+.045	+.032	+.011	+.022	+.024	+.018	+.021
98.77.....	+.010	+.029	+.020	+.011	−.006	+.002	+.011	.....	+.011

TABLE II.

VERTICAL SPARK.

Mean displacements taken from Table I. Results of six series of plates in which length of primary gap, length of secondary gap, capacity, etc., are severally the variables. Displacement of spark lines toward red in tenth-meters: positive unless otherwise indicated.

CONDITIONS	Plate numbers		3, 4	13, 14	11, 12	1, 2	15,16,28	17, 19	20, 21	1, 2	9, 10	7, 8	4a,5,6	23, 29	4a,5,6	26, 27	1, 2	24, 25	1, 2
	Date of exposure		Dec. 29	Dec. 31	Dec. 31	Dec. 29	Jan. 3, 5	Jan. 3	Jan. 3	Dec. 29	Dec. 30	Dec. 30	Dec. 30	Jan. 5	Dec. 30	Jan. 5	Dec. 29	Jan. 5	Dec. 29
	Length of primary spark gap in mm.		20	10	10	1	5	5	5	1	1	1	1	1	1	1	1	1	1
	Length of secondary spark gap in mm		0	0	0	0	0	10	20	0	0	0	0	0	0	0	0	0	0
	Capacity in plates of condenser		9	9	9	9	9	9	9	9	19	38	77	77	77	9	9	9	9
	Self induction in henries		0	0	0	0	0	0	0	0	0	0	0	0.000426	0	0	0	0	0
	Impedance in primary transformer circuit		0	0	0	0	0	0	0	0	0	0	0	0	0	2 4	0	0	0
	Field circuit resistance in ohms		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75	0
	Fan running		No	No	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
	LINE [1]	INTENSITY	(1) LENGTH OF PRIMARY SPARK-GAP				(2) LENGTH OF SECONDARY SPARK-GAP			(3) CAPACITY [3]				(4) SELF-INDUCTION		(5) IMPED-ANCE		(6) FIELD CIRCUIT RESISTANCE	
RESULTS	3900.68	5[2]	0.004	0.017	0.012	0.034	0.014	0.027	0.041	0.034	0.036	0.040	0.043	0.010	0 043	0.031	0.034	0.029	0,034
	04.95	7	−.004	−.003	.010	.022	−.006	−.004	.023	.022	.....	.....	.027	−.004	.027	.007	.022	−.001	.022
	13.58	5[2]	.004	.010	.010	.038	.011	.031	.042	.038	.038	.042	.041	.002	.041	.022	.038	.017	.038
	98.77	8	−.004	−.014	.007	.024	−.003	.009	.025	.024	.	.....	.030	−.002	.030	−.001	.024	.003	.024

[1] Wave-lengths and intensities from Hasselberg's table of the arc spectrum of titanium.

[2] In the spark spectrum lines 3900.68 and 3913.58 are stronger than 3904.93 and 3998.77.

[3] For values of condenser plates in meters and microfarads, see Table III.

[4] Impedance of unknown amount.

that the average displacement for two cadmium lines increases but slowly between 48 and 70.2 meters; and Mohler remarks that "this seems to indicate that the pressure in the spark does not increase directly with the capacity, but, as indicated by Haschek and Mache, the pressure approaches a maximum value."[1] (Haschek and Mache had inclosed the spark in a receptacle and measured the pressure developed when the discharge passed. They used a spark-gap of 2 mm between brass terminals 3 mm in diameter and produced the spark by a transformer which gave "5,200 volts effective" potential.)

TABLE III.

Condenser capacities in meters and microfarads.

No. of plates of condenser	Meters	Microfarads
9	59.4	0.0066
19	125.1	0.0139
38	249.3	0.0277
77	504.3	0.0560

TABLE IV.

HORIZONTAL SPARK.

Mean displacements taken from Table I. Part of spark exposed and spark length are severally the variables. Displacements of spark lines toward red in tenth-meters: positive unless otherwise indicated.

Conditions	Plate numbers		34, 35	36, 37	38, 39
	Date of exposure		Jan. 16	Jan. 16	Jan. 16
	Length of spark-gap in mm		20	20	1
	Capacity in plates of condenser		9	9	9
	Self induction in henries		0	0	0
	Impedance in primary transference circuit		0	0	0
	Field circuit resistance in ohms		0	0	0
	Fan running		No	No	No
	Line	Intensity	Part of Spark Exposed		
			Near terminal	Near center	Near center
Results	3900.68	5	0.058	0.023	0.026
	04.95	7	0.020	0.014	.....
	13.58	5	0.045	0.022	0.021
	98.77	8	0.020	0.002	0.011

[1] Astrophysical Journal, 9, 351, 1899.

In view of this it seems extremely improbable that an increase in capacity from 504 to 625 meters would increase the displacement from 0.043 (the maximum shift obtained by the writer for λ 3900.68—see plates 4a, 5 and 6) to 0.13 tenth-meter.

Haschek states that the transformer and induction coil give different positions for the spark lines—which, indeed, is probably the case. Difference in energy consumption is assigned as the explanation[1] of the difference in spark pressure as found by Mohler, and by Haschek and Mache.[2] This will not explain the larger displacements given by Haschek, for the writer used quite as powerful apparatus, if not more so. In Plates 20 and 21, for instance, the potential difference on the terminals of the primary circuit of the transformer was 77 volts, the current flowing 21 ampères, and the resultant power by actual measurement 1000 watts. The secondary voltage was about 10,500. Haschek's "spark was produced by a high potential transformer supplied by a primary current of 12 ampères and 100 volts, which transformed up to about 10,000 volts." Therefore difference in transformer would not be likely to produce such a difference in displacement.

Another matter may be touched upon at this point. Table IV shows that near the center of the spark gap the displacement is less than near the terminals. After discussing the work of Haschek and Mache "On the Pressure in the Spark,"[3] Haschek writes:[4]

> An explanation of the origin of spark pressure may be found in the investigation of Schuster,[5] who observed that the small particles of the metallic vapor discharged from the electrodes move with great velocity, which diminishes sharply with increasing distance from the electrodes. From this it follows that the particles crowd together toward the middle of the path of the spark, so that the pressure increases with the distance from the electrode. A conception of how the pressure affects the wave-length of the emitted light may be obtained by considering that, upon a sufficiently close approach, the particles must exert mutual forces upon each other. These

[1] ASTROPHYSICAL JOURNAL, **14**, 198, 1901.

[2] *Ibid.*, **12**, 50, 1900. [3] *Ibid.*, **9**, 347, 1899. [4] *Ibid.*, **14**, 188, 1901.

[5] *Nature*, **57**, 1899; *Phil. Trans.*, **193**, A, 1899.

light-producing particles will then no longer vibrate freely, but under the influence of a dampening which causes an increase of wave-length.

This reasoning is not clear to the writer. If we are justified in assuming that the kinetic theory of gases is applicable to the metallic particles of the luminous source, we have:

$$p = \tfrac{1}{3}\, m\, n\, u^2,$$

where p is the pressure exerted by the conglomeration of the particles, m the mass of a particle, n the number of particles, and u^2 the "mean squared velocity."

Even if n increased toward the center of the spark gap, the conclusion could not be drawn that the pressure was greater at this point, for the decrease in the value of u^2 might more than compensate for the increase of n. The fact is that there are probably, in general, more glowing metallic particles near the terminals than in an equal volume at a point midway between them, as is shown (1) by the time of exposure necessary in the two cases to photograph the lines investigated—either with vertical or horizontal spark gap, this being especially true of the lines λ 3900.68 and 3913.58, which appear much enhanced near the terminals;[1] and (2) by the results obtained by Schenck[2] who states that "the principal spark lines show a tendency to shorten up close to the poles, while the arc lines go clear across the gap." Of course, we may not be justified in using the word "pressure" with reference to the spark, because in a phenomenon such as this the motion of the particles is so irregular that the term "mean squared velocity" may well be regarded as having no physical meaning. Moreover, in general, it may not be justifiable to base any line of reasoning on conclusions drawn from the kinetic theory of gases.

All that may be said is that, if increase of pressure in the spark produces an increase in the wave-length of the line, the pressure near the terminal is greater than that in the center of the spark.

[1] Schuster states that "the metallic vapors remain luminous in the center of the spark for a longer period than near the poles." However, the intensity of illumination appears—for the characteristic spark lines at least, if not indeed for the rest as well—greater near the "pole."

[2] ASTROPHYSICAL JOURNAL, 14, 129. 1901.

To study further the effect of inserting self-induction in the discharge circuit of the condenser there was taken somewhat later a series of plates covering the region λ4200 to λ4700, one set with 0.000426 henries self-induction and the other with none.

TABLE V.

Relative positions of spark and arc lines observed with and without self-induction in the discharge circuit of the condenser. M=mean displacement of spark line.

Line	Displacement for Separate Plates					
	41	42	M	45	46	M
4443.97	−0.015	−0.029	−0.022	−0.007	−0.008	−0.007
55.48	.051	.046	.048	.003	.006	.004
68.65	.030	.033	.031	000	.006	.003

TABLE VI.

Mean displacements taken from Table V. Self-induction is the variable. Displacements in tenth-meters: positive toward the red.

Conditions			
	Plate numbers	41, 42	45, 46
	Date of exposure	Jan. 17	Jan. 17
	Length of spark gap in mm	1	1
	Capacity in plates of condenser	77	77
	Impedance in primary transference circuit	0	0
	Field circuit resistance in ohms	0	0
	Fan running	No	No

Results	Line	Intensity	Self-Induction in Henries	
			0	0.000426
	4443.97	6	−0.022	−0.007
	55.48	6	.048	.004
	68.65	6	.031	.003

Table V shows the agreement of the measurements made upon the members of each set; and Table VI gives the condition under which the plates were taken. It will be noticed in the case of λ4443.97 that the insertion of self-induction appears to place the line farther toward the red—an exception to the general rule found above.

The results of this brief survey of the questions considered may be summed up as follows:

1. When a spark spectrum is obtained for purposes of measurement, the conditions under which it is taken should be stated more fully than is customary at present, for the position of the lines is altered to more than a negligible degree by the condition of the electric circuit as to capacity, self-induction, resistance in field circuit of alternator, and impedance in primary circuit of transformer.

2. Different parts of the spark give spectra in which the lines have not only different relative intensities, but different wave-lengths.

That the wave-lengths depend upon the capacity and the apparatus used, whether induction coil or transformer, has been known for some time. That self-induction alters the position of the lines, and that the part of the spark exposed enters as important factors, are facts which had not come to the writer's notice.

3. Such large displacements, as are given by Haschek for the lines of the *Ti* spectrum have not been found here.

It must be clearly understood that the grating used is not one which possesses a dispersion fully adequate for an accurate quantitative study of the question in hand; and that, with the dispersion given, the limit of accuracy of measurement lies far too near the magnitude of the effects studied. However, the collateral evidence is so strong that the results here given are undoubtedly qualitatively correct. Moreover, it appears impossible to attribute the persistent and regular changes in the positions of the spark lines to mechanical motion in the apparatus, unequal illumination of the grating, heating of the slit, errors in measurement, or, in short, to any other causes than those given

above. The writer intends, as soon as possible, to continue the research with a larger grating.

In conclusion I wish to acknowledge my indebtedness to Professor Hale for proposing the investigation, to both Professor Hale and Professor Frost for their valuable suggestions, and to Messrs. Ellerman and Fox for their assistance in the laboratory during the latter part of the investigation.

WABASH COLLEGE,
Crawfordsville, Ind., April 7, 1903.

Minor Contributions and Notes.

THE NEW STAR IN *GEMINI*.

Telegraphic announcement of the discovery on March 16 of a new star in *Gemini* by Turner (presumably on the Oxford photographs) was received at the Yerkes Observatory on the afternoon of March 27. The same evening the star was observed with the forty-inch refractor. Its conspicuous red color was at once explained by the great intensity of the *Hα* line, as observed by Mr. Ellerman and the writer with a direct vision spectroscope. Very bright lines in the yellow and blue were clearly visible on a faint background of continuous spectrum. The star thus presented the familiar characteristics of *Novæ*.

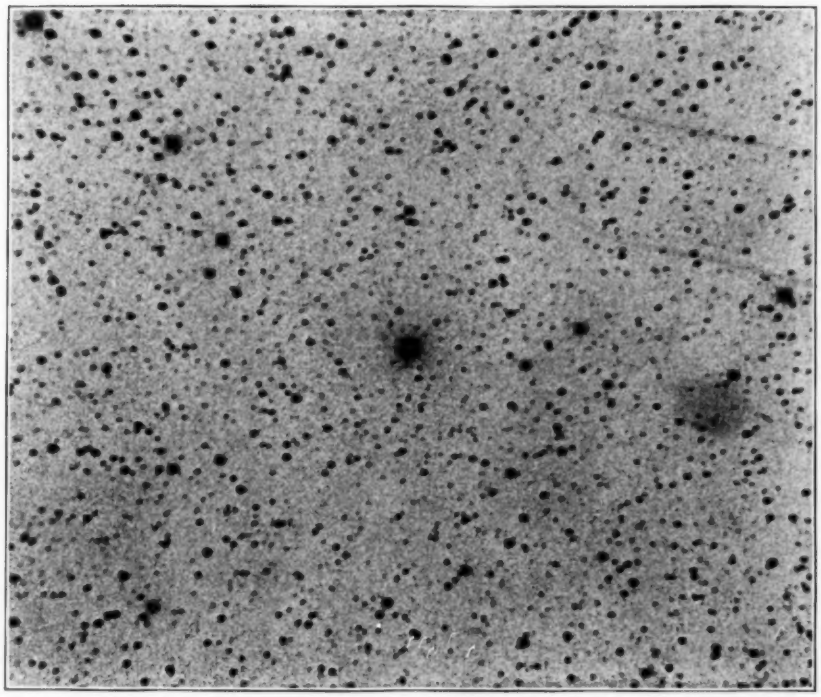
The region of the *Nova* had been photographed with the two-foot reflector by Mr. Parkhurst on February 21, 1903, for the purpose of charting the field around the variable star 2404 *X Geminorum*, which lies two-thirds of a degree east. The exposure time was 20 minutes, from $8^h\ 22^m$ to $8^h\ 42^m$ C. S. T. After the receipt of the telegraphic announcement of Professor Turner's discovery, Mr. Parkhurst carefully examined the region of the *Nova* on this plate. What appeared to be an image of the *Nova* was found. It is a little brighter than the fifteenth magnitude, the faintest stars visible in the vicinity being about half a magnitude fainter. Careful comparison with similar plates taken since the *Nova* brightened, and also with the sky as seen in the large telescope, indicates that the star photographed is either the *Nova* or a fifteenth magnitude star within three seconds of arc of the place. The comparison certainly shows that the *Nova* was not brighter than the fifteenth magnitude on February 21.

The region of the *Nova* was photographed with the two-foot reflector by Mr. Pease on March 28 and 29 with a total exposure of 8¾ hours (Plate XXI). As the conditions were fairly good during the exposure of this photograph, it seems probable that no bright nebulosity, like that surrounding *Nova Persei*, existed at this time in the vicinity of *Nova Geminorum*.

Position.—Micrometric measures with the 40-inch refractor by Professor Barnard gave the following positions for the new star with respect to *B. D.* 29°.1342 (8.2 mag.):

PLATE XXI.

N.



Scale: 1 mm = 20″. S.

PHOTOGRAPH OF THE REGION OF *NOVA GEMINORUM.*

Date	*Nova*—Star	
March 27....	$\Delta\alpha$ -2^m $21^s.84$	$\Delta\delta$ $+5'$ $57''.29$
March 30....	-2 21.76	$+5$ 57.25
	-2 21.80	$+5$ 57.27

In the observations of March 27, an intermediate star was used in both $\Delta\alpha$ and $\Delta\delta$, and on the 30th in $\Delta\alpha$.

Mean place of comparison star for 1900.0	Authority.
$\alpha = 6^h\ 40^m\ 10^s.79$; $\delta = +29^\circ\ 56'\ 42''.05$.	Leiden *A. G. C.* 2813 and Cambridge *A. G. C.* 3482.

It was observed twice at Leiden and three times at Cambridge; the declinations differ by $1''.7$, which does not appear to be due to motion. These two positions were weighted according to the number of observations.

The following position results for the *Nova*:

1900.0 $\alpha = 6^h\ 37^m\ 48^s.99$. $\delta = +30^\circ\ 2'\ 39''.3$.

The star is of a strong red color—redder than *B. D.* $+29^\circ.1342$.

Micrometric measures have been made of the small stars near the *Nova* to form an accurate chart for detection of possible motion in the *Nova*. The measures so far made are given below. The stars may be identified from the accompanying drawing (Fig. 1) showing the field immediately surrounding the *Nova*.

Nova and $12^m.3$ star following = No. 1.

1903, March 30.....	$104^\circ.82$	$32''.21$
April 4.....	105.22	32.52
	105.02	32.36

Nova and $12^m.6$ star South = No. 2.

1903, March 30.....	$169^\circ.21$	$45''.66$

Nova and $14^m.5$ star North = No. 3.

1903, March 30.....	$341^\circ.61$	$55''.69$

Nova and $12^m.5$ star preceding = No. 4.

1903, March 30.....	196°.15	84′.93
April 4.....	196.30	85.15
	196.22	85.04

Nova and $12^m.5$ star North = No. 5.

1903, March 30.....	313°.86	99′.87
April 4.....	313.90	99.93
	313.88	99.90

Nova and 12^m star North = No. 6

1903, March 30	16°.98	102′.81
April 4.....	17.45	103.00
	17.21	102.90

POSITIONS OF THE SMALL STARS, REFERRED TO THE MEAN EQUINOX OF 1900.0.

	R. A.			Dec.		
No. 5.....	6^h	37^m	$43^s.44$	+30°	3′	48″.5
4.....	6	37	47.16	+30	1	17.6
3.....	6	37	47.64	+30	3	32.1
2.....	6	37	49.65	+30	0	54.5
6.....	6	37	51.33	+30	4	17.6
1.....	6	37	51.40	+30	2	30.9

Focus.—The following observations made by Professor Barnard show that the focus of the *Nova* with the forty-inch refractor did not differ appreciably from that for the comparison star:

		Inches	
	March 27 *Nova* focus	2.12	(4 obs.)
B. D.	+30°1314 "	2.10	(5 obs.)
	Nova − star = +0.02 = +0.51 mm		
	March 30 *Nova* focus	2.13	(9 obs.)
B. D.	+30°1314 "	2.15	(9 obs.)
	Nova − star = −0.02 = −0.51 mm		

When in the best focus there was a decided glow about the star for some 2″ or 3″, which was of a crimson color. This was not present with the other stars. By drawing the eyepiece out, a small, well-defined image of the star was formed of about the tenth magnitude and

about 0".1 in diameter. It was sharply defined and of a beautiful crimson color — far more vivid than Hind's celebrated crimson star. The *Nova* was surrounded by a pale, grayish blue halo 3'.8 in diameter by measurement. This phenomenon was not present when other stars were thrown out of focus.

Five very accordant settings were made for the focus for this crimson image, giving focus = 2.51 inches. This, compared with the observations for the true focus for this star on the same date, showed that this second image, one and a half magnitudes less than the other, was formed 0.38 inch (9.6 mm) outside the proper focus for the *Nova*. This was undoubtedly due to the predominance of the bright *Hα* line in the light of the *Nova*.

Magnitude.—The photometric magnitudes of the *Nova*, as measured on seven nights by Mr. Parkhurst with an equalizing wedge photometer attached to the twelve-inch refractor and six-inch reflector, are as follows:

PHOTOMETRIC MAGNITUDES OF *NOVA GEMINORUM* ON HARVARD COLLEGE OBSERVATORY SCALE.

(To express on Potsdam scale, add 0.20 mag.)

Date.	G. M. T.	Mag.
1903, March	27.715	8.51
	28.636	8.71
	29.603	8.85
	29.650	8.91
	30.673	8.76
	31.588	8.89
April	3.564	8.91 ±
	4.583	8.96

Measured from four standard stars ; mean residual from separate stars, 0.03 mag.

Spectrum.—As neither the position nor the physical characteristics of the bright lines could be determined satisfactorily by visual observations, two of the prisms of the Bruce spectrograph were removed, and a short camera attached for use with a single prism. The camera lens employed was a Unar, series Ib, No. 7, kindly loaned by the Bausch & Lomb Optical Co. pending the construction of a special short focus doublet. A mounting for the camera was made in the instrument shop on March 28, and the spectrum of the *Nova* was photographed on that evening by Professor Frost and Mr. Adams. The

photograph, which is reproduced in Fig. 2, was taken at $15^h\ 40^m$ G. M. T. (middle of exposure), and was exposed for $3^h\ 12^m$. A Cramer isochromatic plate was used, without the correcting lens. Titanium was employed for the comparison spectrum, supplemented by helium, the spectrum of which was photographed on another plate immediately after the end of the exposure for the star.

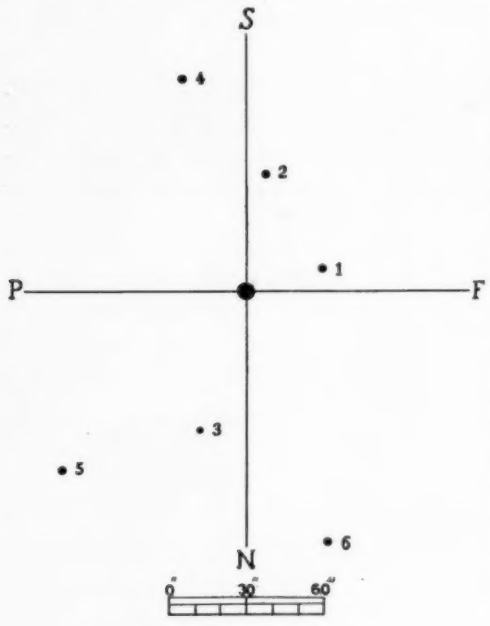


FIG. 1.—Stars near the *Nova*.

Professor Frost's study of this photograph shows that the most conspicuous features are the very strong bright band extending from about λ 4598 to λ 4696 (mean at λ 4647), and the very strong *Hβ* line, extending from λ4839 to λ 4886 (mean at λ4862). There appeared to be two narrow bright maxima near the less refrangible end of *Hβ*, at λ4877 and λ4882. At the less refrangible end of the plate there are two fairly strong bands, one extending from λ 5647 to λ 5685 (mean at λ 5666), the other extending from λ 5729 to λ 5775 (mean at λ 5752). The less refrangible of these lines is rather sharply bounded on the violet side, suggesting the presence of a dark band. The lack of sensitiveness of the plate near λ 5000 may account for the absence of the band near λ 5016, which, though found in the spectra of *Nova Aurigae* and *Nova Persei*, is exceedingly faint in *Nova Geminorum*. *Hγ*, though hardly measurable, is visible on the plate as a very faint band merging into a brighter band which extends from λ 4347 to λ 4371 (mean at λ 4359). The intensity of this part of the spectrum was greatly reduced through the absence of the correcting lens, and the slit was not in the focal plane of the forty-inch telescope for this region. This probably accounts for the decided faintness of *Hγ* as

compared with $H\beta$, but in any case $H\gamma$ would appear to be distinctly fainter than λ 4359.

The spectrum of *Nova Geminorum* thus corresponds with the spectra of *Nova Persei* and *Nova Aurigae* in their later stages of development, particularly with respect to the relative intensity of the bands observed, all of which were present in both of these stars. After the transformation of the spectrum of *Nova Aurigae* into that of a nebula, in August 1892, the intensities of λλ 4358, 4640, 4863, and 5750 were estimated by Campbell as 8, 7, 10, and 10 respectively, and were only exceeded by the chief nebular lines λ 5007 and λ 4959 with intensities of 100 and 30. On the negative of the spectrum of *Nova Geminorum* the very faint bright band in the region of the principal nebular lines is too weak for measurement.

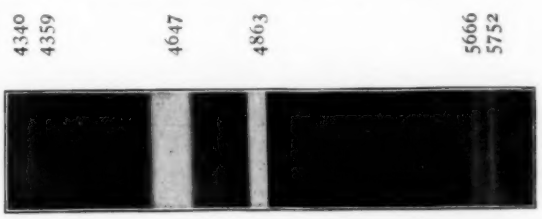


FIG. 2.—Spectrum of *Nova Geminorum*, March 28, 1903.

Visual observations of the *Nova* have been made with a single ocular prism, or direct vision train, on each available night since March 27, but no changes sufficiently obvious to be noticed with such small dispersive power have been observed.

GEORGE E. HALE.

YERKES OBSERVATORY,
April 6, 1903.

NOVA GEMINORUM BEFORE ITS DISCOVERY.[1]

ON March 27, 1903, a cable message was received from Professor Kreutz, of Kiel, stating that an object which was probably a new star, but was possibly a variable, had been discovered by Professor Turner. Also, that on March 16 it was of the magnitude 8.0, while on February 16 it had not been seen (presumably on a photograph). Its apparent place was R. A. $6^h\ 37^m\ 48^s$, Dec. $+30^\circ\ 4'$. The grant from the Carnegie Institution permitted an examination to be made of the early photographs of the Henry Draper Memorial, and furnished the history of this object from its first appearance to the present time. An excellent photograph of the region, taken 1903, March $1^d\ 15^h\ 3^m$, G. M. T., showed stars of the magnitude 11.9, but no trace of the *Nova* was

[1] *Harvard College Observatory Circular* No. 70.

visible. A similar result was found from sixty-seven plates, the first taken March 3, 1890, the last on February 28, 1903, although nearly all of these plates showed stars fainter than the twelfth magnitude. One or more of these photographs were taken on each intermediate year. It did not therefore seem necessary to examine the other early plates of this region, a hundred or more in number. A plate taken 1903, March 2^d 13^h 19^m, showed stars of the ninth magnitude, but no trace of the *Nova*. The evenings of March 3, 4, and 5 were cloudy, but on a plate taken March 6^d 14^h 28^m, an object of the magnitude 5.08 appears in the given place. Plates taken on several later nights showed that the magnitude was gradually diminishing, as appears in Table I, which gives in successive columns the date, the Greenwich Mean Time, the photographic magnitude of the *Nova*, and the initial of the observer. F. denotes Mrs. Fleming and L. Miss Leland.

The photograph of March 6 has especial value, since, so far as is known, it contains the first photograph of the *Nova*. The image is on the very edge of the plate, and accordingly was compared with fifteen other stars at about the same distance from the center of the plate. The *Nova* was compared twice with each star by each observer. The value of the grade was much larger than usual, and equaled 0.21 and 0.33 for the two observers. The mean result for all was magnitude 5.08, with an average deviation, for the separate stars, of $\pm$ 0.26. The magnitude on each of the other dates given in the table was found by

TABLE I.

PHOTOGRAPHIC MAGNITUDES.

Date	G. M. T.	Mag.	Obs.	Date	G. M. T.	Mag.	Obs.
	h. m.				h. m.		
1903 March 1	15 3	<11.4	L.	1903, March 14	14 14	7.42	F.
2	14 31	< 9.5	F.	14	14 14	7.34	L.
6	14 28	4.97	F.	14	16 20	7.32	F.
6	14 28	5.20	L.	14	16 20	7.34	L.
11	15 18	6.76	F.	15	13 44	7.27	F.
12	14 25	7.06	F.	15	14 53	7.57	F.
12	15 25	7.16	F.	15	14 53	7.46	L.
13	14 52	7.12	F.	25	13 26	7.94	L.
13	14 52	7.17	F.	25	13 39	8.08	F.

comparison with six stars whose brightness was nearly equal to that of the *Nova*. These magnitudes were derived assuming that the photometric and photographic magnitudes were nearly the same for stars whose spectra were of the first type.

The evening of March 27 was cloudy and also the early part of March 28. One plate, however, taken on the latter date, gave the magnitude 8.34. Several photographs were taken on March 29, 31, and April 1, and gave the mean magnitudes 8.24, 8.24, and 8.25. These magnitudes are based upon the results given in Table II, which contains the designations, *Durchmusterung* numbers, rectangular coordinates expressed in seconds of arc with the *Nova* as an origin, and provisional photographic magnitudes of a sequence of comparison stars. It is probable that the fainter stars are really fainter than these magnitudes indicate, but the latter will serve to determine the relative changes in the *Nova* as it grows fainter, and thus render the results of different observers comparable. All the magnitudes can later be reduced to an absolute scale. They also serve to compare the faintest stars shown on early plates. Thus, the photograph taken March 1, 1903, shows star *t*, and also stars at least a tenth of a magnitude fainter. Star *u* does not appear. Hence this plate shows stars of the magnitude 11.9 and brighter.

The last plate in Table I is of interest, since it was taken with an objective prism, and accordingly shows the spectra of the *Nova* and of the adjacent stars. Six bright lines are shown in the spectrum of the *Nova*, whose designations, assumed wave-lengths, and intensities, calling the intensity of the line $H\gamma$, *10*, are as follows: $H\zeta$, λ 3889, *1*; $H\epsilon$, λ 3970, *3*; $H\delta$, λ 4102, *8*; $H\gamma$, λ 4341, *10*; —, λ 4643, *11*; $H\beta$, λ 4862, *9*.

TABLE II.

COMPARISON STARS.

Des.	*B. D.*	*x*	*y*	Mag.	Des.	*B. D.*	*x*	*y*	Mag.
		″	″				″	″	
a	+30° 1318	+ 716	+3187	7.28	*p*	.....	+ 4	+368	11.19
b	+30° 1300	.....	.....	7.76	*q*	.....	+308	−132	11.41
c	+30° 1314	+ 274	+1949	7.98	*r*	.....	−404	−278	11.63
d	+30° 1320	+1021	+ 878	8.50	*s*	.....	+359	+345	11.73
e	+29° 1342	+1843	− 347	8.82	*t*	.....	−224	+176	11.78
f	+30° 1316	+ 643	+ 552	9.14	*u*	.....	+467	+145	12.08
g	+30° 1306	−1006	+ 142	9.36	*w*	.....	−254	+242	12.23
h	... .	+ 504	+ 289	9.71	*x*	.....	−268	+ 92	12.45
	... ...	+ 504	+ 297		*y*	.....	+270	+ 16	12.70
k	+30° 1302	−1923	+ 231	9.93	*z*	.....	+186	− 64	12.95
l	+30° 1309	− 456	+ 53	10.13	α	.....	+ 31	+ 97	13.05
m	+30° 1317	+ 638	− 327	10.41	β	.....	− 24	− 76	13.35
n	... .	− 311	− 47	10.66	γ	.....	+ 31	− 8	13.53
o	... .	+ 544	+ 197	11.01					

From this it appears that the spectrum resembles that of *Nova Sagittarii* on April 19, 1898. No dark lines are visible, but this is perhaps owing to the small dispersion.

The same lines, and having nearly the same intensities, appeared on similar photographs taken on March 29, 31, and April 1. They also showed the additional nebula line, λ5003, which has the intensity *2* or *3*, and is certainly brighter than *Hζ*. This line does not appear on the plate taken March 25, and indicates the first step in the change into a gaseous nebula. Three additional bright lines were detected in the later photographs, whose estimated wave-lengths are about λ4176, 4240, and 4462.

In the other new stars the appearance of line 5003 was followed by the diminution in intensity of the line *Hβ*, and the appearance and rapid increase in the nebula line, near *Hζ*, which finally became the strongest line in the spectrum.

A most important question in connection with the appearance of new stars is whether such objects can come and go without detection by astronomers. Since the Henry Draper Memorial was established, nine new stars have been discovered. Six of them, *Nova Persei* No. 1, *Nova Normae*, *Nova Carinae* No. 2, *Nova Centauri*, *Nova Sagittarii*, and *Nova Aquilae*, were found in the regular examination of the Draper Memorial photographs, and probably all of them would otherwise have escaped detection. Two, *Nova Aurigae* and *Nova Persei* No. 2, were bright, and were found visually by Dr. Anderson. The first of these might have escaped detection here, although numerous early charts were obtained which showed that it was visible to the naked eye during seven weeks before its discovery. The spectrum of Turner's *Nova* is so conspicuous on the plate taken on March 25 that when this plate was developed and examined it would doubtless have been found on it here, but for the prompt discovery and announcement by Professor Turner.

EDWARD C. PICKERING.

APRIL 3, 1903.

A LIST OF FOUR STARS WHOSE VELOCITIES IN THE LINE OF SIGHT ARE VARIABLE.[1]

THE following four spectroscopic binaries, discovered with the Mills Spectrograph, are additional to the thirty-eight binaries already announced:

[1] *Lick Observatory Bulletin* No. 31.

ν Andromedae ($\alpha = 0^h\ 44^m$; $\delta = +40^\circ\ 32'$).

The variable velocity of this star was discovered from the second plate. Three observations have been secured, as follows:

Date	Velocity	Measured by
1902, October 8	− 17 km	Curtis
November 5	− 76	Curtis
1903, January 14	+ 49	Curtis

The spectrum of this star shows very few lines. The *Hγ* line is very broad, but the lines due to helium are much better and admit of fairly accurate measurements.

π⁴ Orionis ($\alpha = 4^h\ 46^m$; $\delta = +5^\circ\ 26'$).

The variation in velocity was discovered from the second plate, the observations being as follows:

Date	Velocity	Measured by
1902, October 6	+ 43 km	Curtis
1903, January 4	± 0	Curtis
January 12	+ 6	Curtis

The spectrum is very similar to that of *ν Andromedae*.

σ Geminorum ($\alpha = 7^h\ 37^m$; $\delta = +29^\circ\ 7'$).

The change in velocity was shown in the second plate of this star. The observations are as follows:

Date	Velocity	Measured by
1902, March 16	+ 74 km	Reese
1903, January 12	+ 12	Reese
January 13	+ 9	Reese
February 15	+ 69	Curtis

The lines in the spectrum of this star, though numerous, are rather hazy. Still they admit of trustworthy measurements.

ι Argus ($\alpha = 8^h\ 3^m.3$; $\delta = -24^\circ\ 1'$).

Director Campbell requests me to announce also the variable

velocity of ι *Argus*, discovered by him in 1898 from the second plate.

Date	Velocity	Measured by
1897, February 23	+ 41.9 km	Reese
1898, February 21	+ 49.5	Reese
1899, April 12	+ 49.8	Reese
April 13	+ 50.3	Reese
1901, April 9	+ 42.3	Reese
1902, February 18	+ 46.3	Reese

H. M. REESE.

FEBRUARY 21, 1903.

A STAR WITH A GREAT RADIAL VELOCITY.[1]

THE star ϕ^2 *Orionis* ($\alpha = 5^h\ 31^m$; $\delta = +9^\circ\ 15'$) is interesting on account of its great velocity in the line of sight. The observations are as follows:

Date	Velocity	Measured by
1902, October 28	+ 94 km	Curtis
November 24	+ 102	Curtis
December 30	+ 96	Curtis

Although the spectrum shows reasonably good lines, it is not likely that the range of eight kilometers in these measurements indicates a real variability in the star's motion, for the second plate was much underexposed.

H. M. REESE.

FEBRUARY 19, 1903.

THE SPECTRUM OF THE NEBULOSITY SURROUNDING *NOVA PERSEI*.[2]

THE remarkable changes of position and brightness observed in the nebulosity around *Nova Persei* have made it desirable to accumulate as much evidence as possible bearing upon the nature of these phenomena.

Unfortunately, physical observations were not attempted during the earlier stages, when the nebulosity was brighter. At the time of the discovery of these changes, it seemed unlikely that any satisfactory

[1] *Lick Observatory Bulletin* No. 31. [2] *Lick Observatory Bulletin* No. 33.

spectroscopic observations could be obtained, owing to the faintness of the nebulosity. The great uncertainty as to the real nature of the changes and the almost entire lack of positive evidence seemed to warrant the attempt, notwithstanding the difficulties.

A small slit-spectrograph, to be used with the Crossley Reflector, was designed especially for the problem. Both collimator and camera lenses are single and of quartz; the prism is also of quartz, the refracting angle being 50°. Following are the constants of the spectrograph, including those of the telescope:

Aperture of lenses and prism	1⅛ inches
Focal length of collimator and camera lenses	6 inches
Refracting angle of prism	50° 14′
Aperture of Crossley Reflector	36¼ inches
Focal length of Crossley Reflector	210 inches

The prism and lenses were mounted directly in frames of brass and attached to the body of the spectrograph, which was constructed of Spanish cedar. A reflecting slit was used, and guiding was accomplished by means of the reflected image of the *Nova* viewed in a small telescope. The nebular spectrum occupied the central 0.2 inch of the slit, on either side of which was photographed a comparison spectrum of hydrogen. The slit-width was reduced to 0.002 inch for the comparison spectrum, which was inserted for from 2^s to 5^s each night at about the middle of the exposure.

The photographs of the *Nova* in August and September 1902, with exposures of 7 to 11 hours, showed only condensation *D* with any certainty. No attempt was made, therefore, to study any other portion of the nebula. The slit was placed approximately parallel to a circle of declination, and by estimation across the densest part of condensation *D*. This region was free from small stars. The region covered was 1½′ south and from 1′ west to 4′ west of the *Nova*.

Under the above conditions and with a slit-width of 0.006 inch, a negative was obtained with the following exposures:

Duration		Remarks
1902, October 31,	$7^h\ 40^m$	Seeing 2; sky good.
November 1,	9 4	Seeing 3; haze in the beginning.
November 2,	8 0	Seeing 3; some haze in the beginning; stopped by clouds.
November 4,	9 25	Seeing 3; sky good.
Total,	$34^h\ 9^m$	

The resulting negative shows a very faint spectrum extending from $H\beta$ to about λ 360. The length of the spectrum is 0.11 inch. There is no evidence of flexure in the spectrograph, nor of any change in the position of the plate during the exposure. As the exposure on October 31 had been carried through the first traces of dawn, a negative was made, later, under as nearly the same conditions as possible, to make sure that the spectrum obtained was not that of the sky. No trace of any sky spectrum was found on this plate. Another plate which had been exposed in the brighter dawn to obtain a faint spectrum of the sky for comparison, showed that the sky spectrum was unlike that of the nebula which had been obtained. With such low dispersion the sky spectrum between $H\beta$ and K is divided into two bands of almost equal extent and intensity by the weaker region (full of absorption lines) at G. These and other considerations seem to leave no doubt that the spectrum obtained is that of the nebulosity.

In the spectrum of the *Nova* nebula fully three-fourths of the light is condensed in the region extending from $H\beta$ to $H\gamma$; above $H\gamma$ the spectrum is extremely faint, and is lacking entirely from about λ 380 to λ 390. In the upper part of the spectrum there appear to be traces of two lines, one almost coincident with $H\delta$ and the other at about λ 370. They are so extremely faint, however, that their existence cannot be affirmed with certainty.

If the above interpretation is correct, the spectrum of condensation *D* resembles that of the *Nova* during the first few days of its great brightness much more than it does that observed since July 1901. So far as can be told from the low dispersion used and the weak spectrum recorded, the general appearance of the spectrum of the nebula below λ 380 agrees very well with the spectrum of the *Nova* obtained by Campbell and Wright in February 1901. With the conditions under which their observations were made most of the light of the *Nova* would be included in the region between $H\beta$ and $H\gamma$, and the region between λ 380 and λ 390 would be too weak to show in a faint spectrum. This is also true of the region below $H\beta$. As no early observations of the spectrum of the *Nova* high up in the violet have been published, it is impossible to make any comparisons between the two spectra in this region, where some lines are suspected in the nebulosity.

The spectrum of the nebulosity does not agree with that of the *Nova* observed since July 1901. The strongest region in the spectrum of the nebulosity may possibly be made up of the lines between $H\beta$ and $H\gamma$ which the low dispersion failed to separate in a spectrum so

weak, although this seems improbable. The positions of the two suspected lines at λ 410 and λ 370 do not agree at all, however, with the strongest lines in the later spectrum of the *Nova*. There are certainly no traces in the nebulosity of any lines in the positions of those observed in the *Nova* at λ 387 and λ 397 by Campbell and Wright,[2] nor at λ 346, where a very strong line was photographed by Mr. Stebbins,[1] with the Crossley Reflector. These lines are the strongest in the photographic spectrum of the *Nova* since July 1901.

The spectrum obtained is certainly not the ordinary bright-line spectrum of the nebulæ. The suspected lines at λ 410 and λ 370 may be nebular lines which occupy approximately these positions. The region between $H\beta$ and $H\gamma$, however, is not at all like the characteristic nebular spectrum, where $H\beta$ and $H\gamma$ (and occasionally λ 469) are the only strong lines. If the ordinary nebular spectrum is present at all, it is in conjunction with another spectrum, probably continuous, extending from λ 434 to λ 487.

To still further test the identity of the spectrum secured, three negatives of the spectrum of the *Nova* were obtained on February 17, 1903, with the same spectrograph. Exposures of 10, 30, and 60 minutes were given. Ten minutes barely sufficed to give a distinguishable spectrum. One hour gave a spectrum showing the five principal lines between λ 387 and λ 471. There are traces of the chief nebular line, and a very faint spectrum up in the ultra-violet. The relative intensities of the lines are not very different from those obtained in September and October 1901, by Mr. Stebbins with the small slitless spectrograph attached to the Crossley Reflector.

A comparison of the spectrum of the *Nova* on February 17, 1903, and that of the nebulosity, shows that they are not identical. The line at λ 387, which is one of the strongest in the spectrum of the *Nova*, has no counterpart whatever in the nebula. It cannot be made to coincide with the slight strengthening in the nebula at λ 370.

The conclusions are, therefore, that the spectrum of condensation *D* observed in November 1902, is not the spectrum of a gaseous nebula; that it is not the spectrum of the *Nova* since the latter has become nebular; and that it more nearly resembles the spectrum of the *Nova* during the first few days of its outburst. The question as to what epoch in the star's history the spectrum of the nebulosity should conform, if the light were reflected, is a difficult one to decide with the data in our possession. This is particularly true in the case of con-

[1] *Lick Observatory Bulletin* No. 8.

densation *D*. Some knowledge of the real distance and direction of this mass from the star, or spectroscopic observations at considerable intervals, would aid materially in the solution.

The preceding spectroscopic evidence is not inconsistent with the theory that the light of condensation *D*, at least, is reflected light emitted by the *Nova at the time of its greatest brightness;* but is not strong enough to establish this theory in the face of conflicting indications already pointed out.

The spectrum of the thirteenth-magnitude star at approximately the position-angle of 245° and 4½′ distant from the *Nova* is also shown on the negative, this star having occasionally crossed the slit. Its spectrum appears to be continuous, and extends from $H\beta$ to $H\gamma$.

I am indebted to Dr. Campbell for suggestions as to the construction of the spectrograph, and to Dr. H. D. Curtis and Fellows R. H. Curtiss and C. A. G. Weymouth for assistance in making the observations.

C. D. PERRINE.

MARCH 2, 1903.

THE SNOW HORIZONTAL TELESCOPE.

I AM glad to be permitted to announce that Miss Helen E. Snow, of Chicago, has provided for the reconstruction of the coelostat reflecting telescope of the Yerkes Observatory as a memorial to her father, the late George W. Snow. Through Miss Snow's generosity it will be possible to build the telescope in permanent and substantial form, and to provide it with solar and stellar spectrographs, spectroheliographs, and other important accessories. The great superiority of the new instrument will amply compensate for the delay occasioned by the fire of last December.

GEORGE E. HALE.